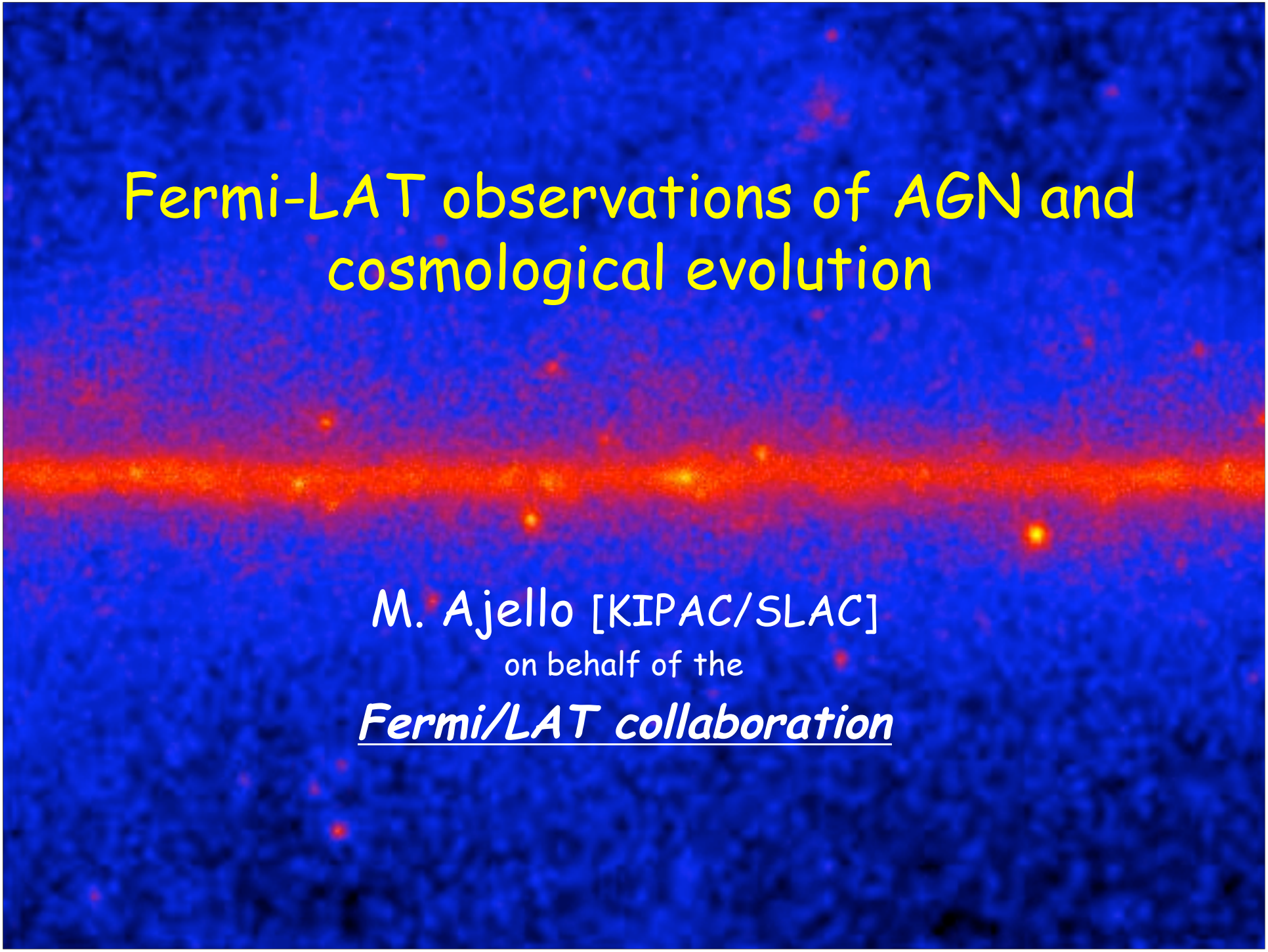


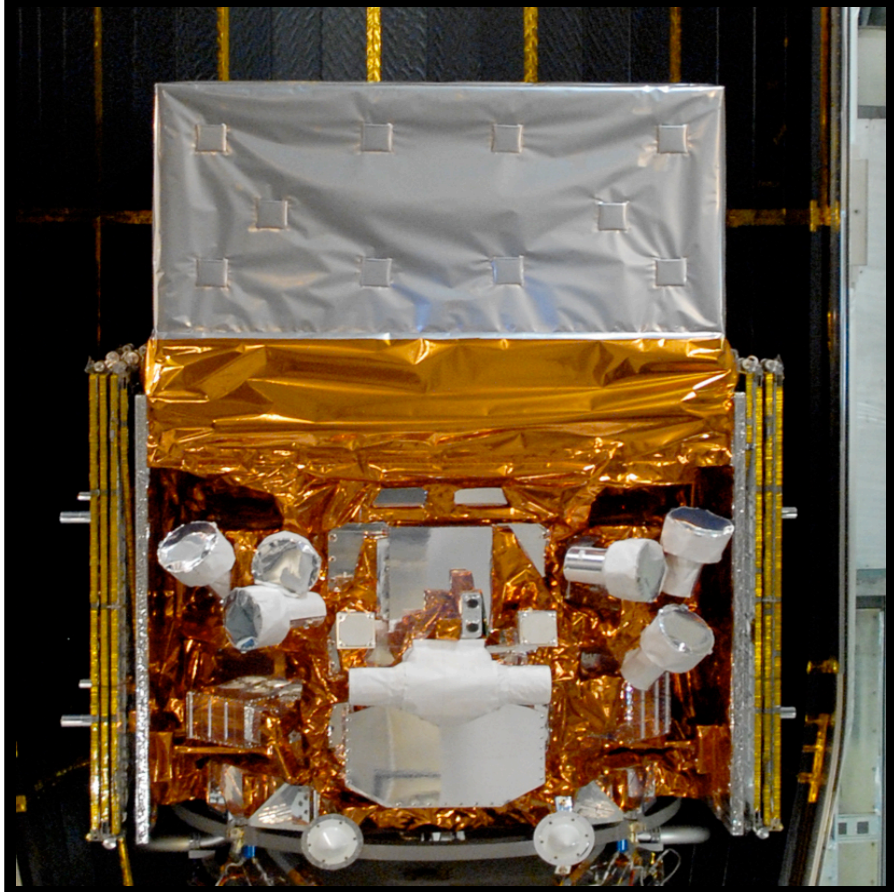
# Fermi-LAT observations of AGN and cosmological evolution

M. Ajello [KIPAC/SLAC]
on behalf of the
***Fermi/LAT collaboration***

# Outline

- Intro on Fermi
- The Fermi 3months sky
- Properties of LAT blazars
- Populations in the LAT sky
- LogN--LogS and Luminosity functions of blazars
- Contribution to the EDB
- Perspectives for the 1yr survey
- Blazars in hard X-rays

# Fermi



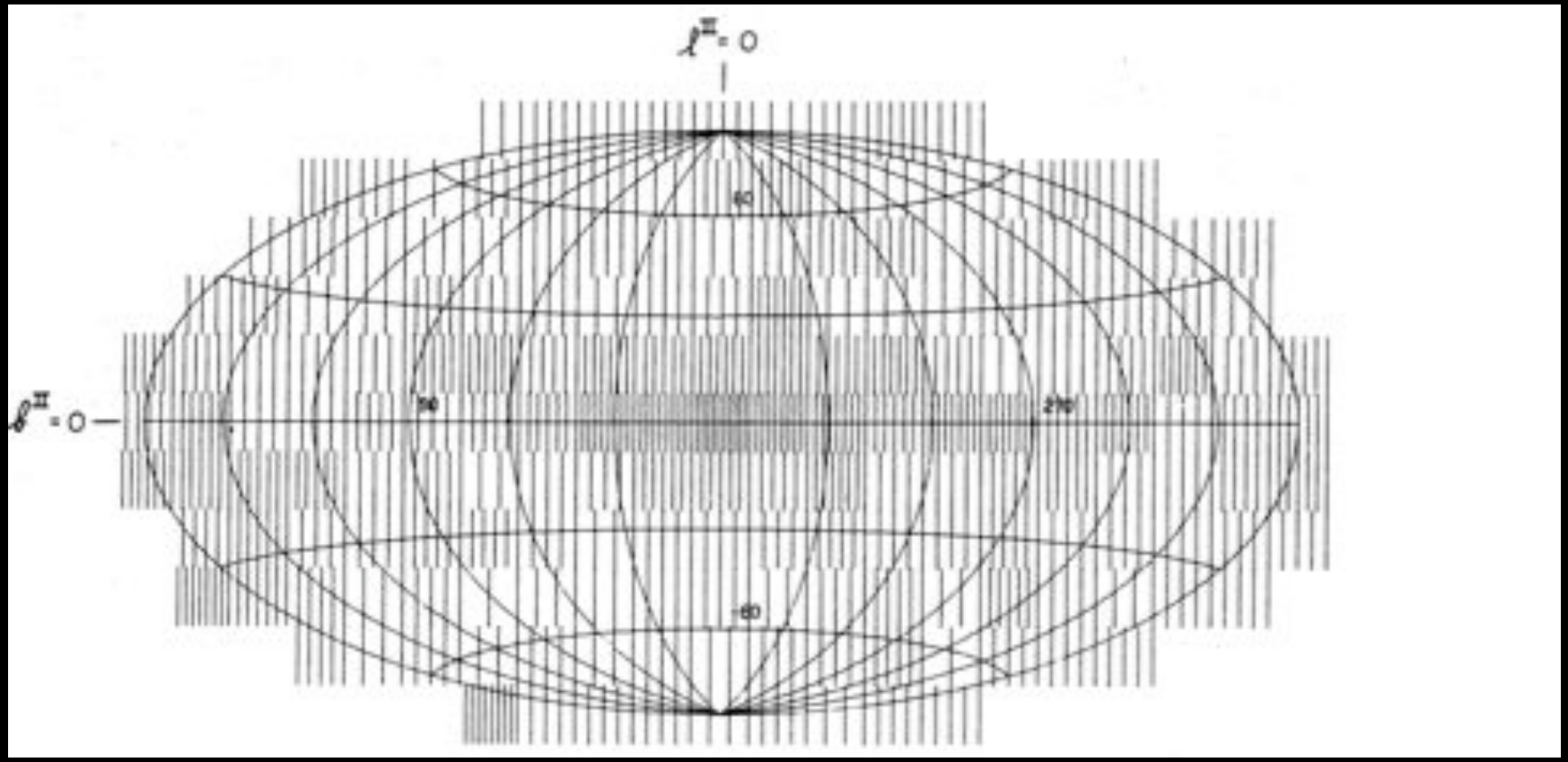
Large Area Telescope (LAT)

- 20MeV – 300 GeV
- 2.4 sr FoV scans the sky every 3hrs

Gamma-ray Burst Monitor(GBM)

- 8 keV – 40 MeV
- Views entire unocculted sky

# The pre-Fermi sky: OSO-3

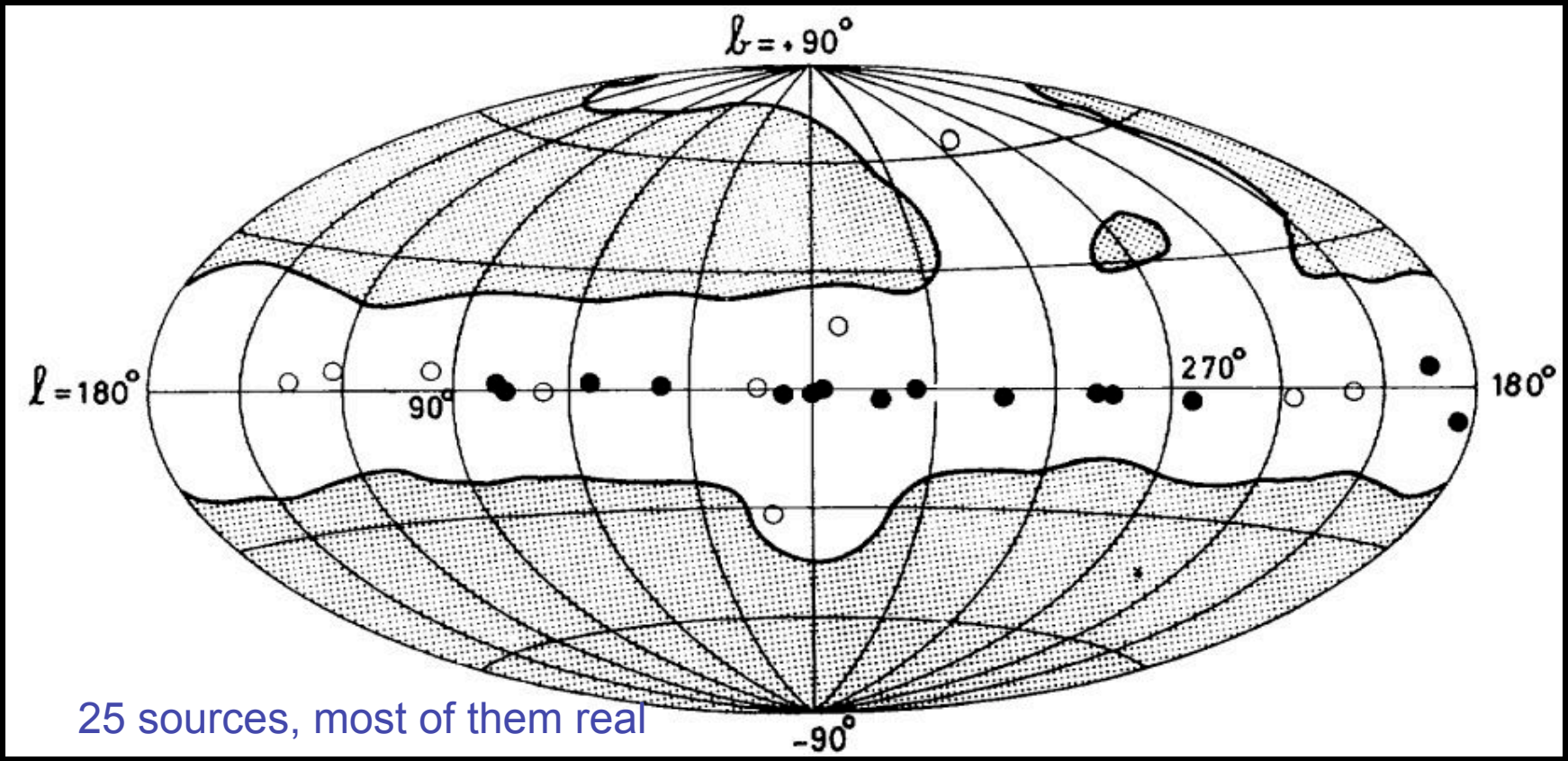



OSO-3 (Kraushaar et al. 1972) 1 source



*Courtesy S. Digel*

# The pre-Fermi sky: COS-B

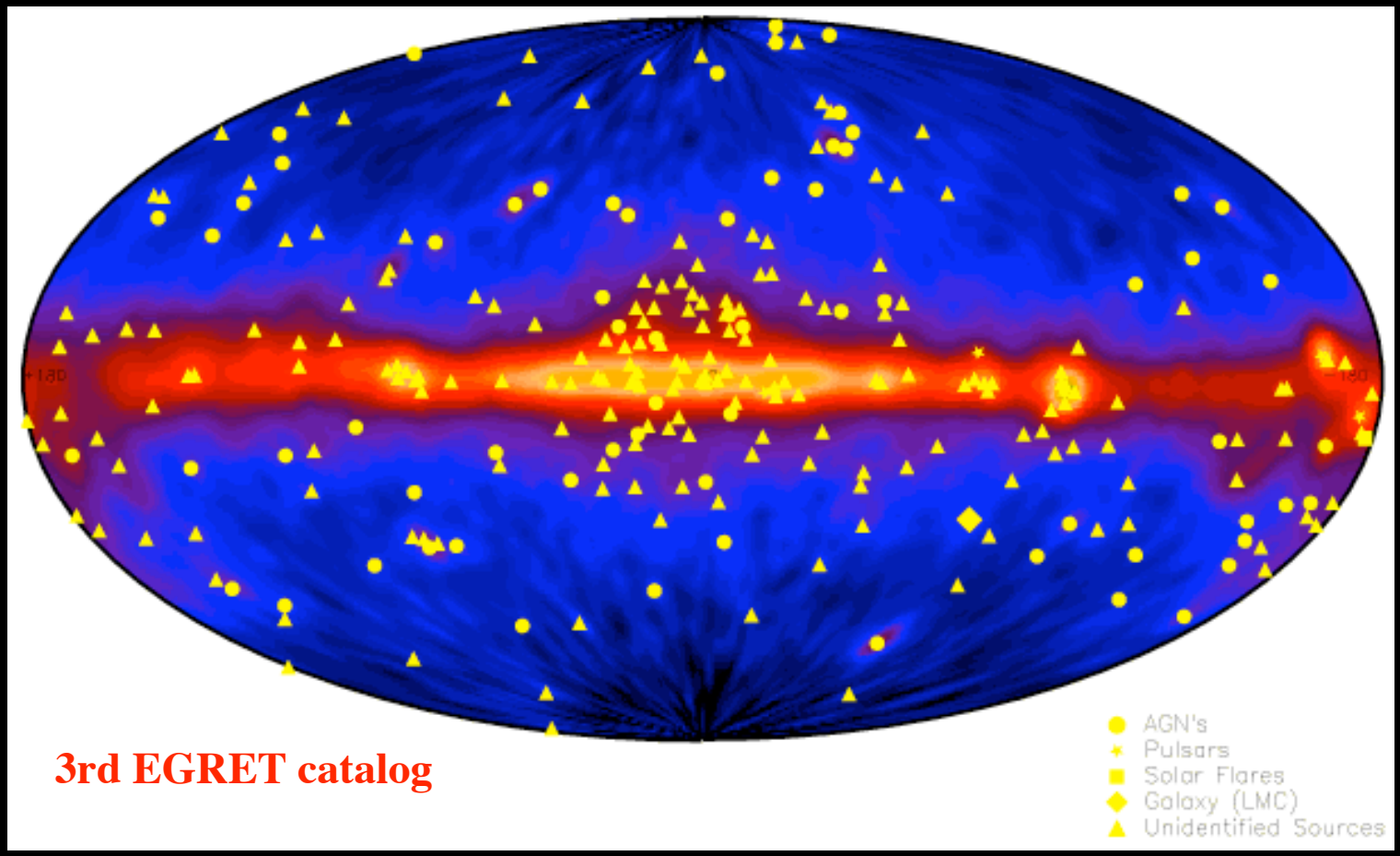



25 sources, most of them real

Swanenburg et al. (1981)

*Courtesy S. Digel*

# The pre-Fermi γ-ray sky: EGRET

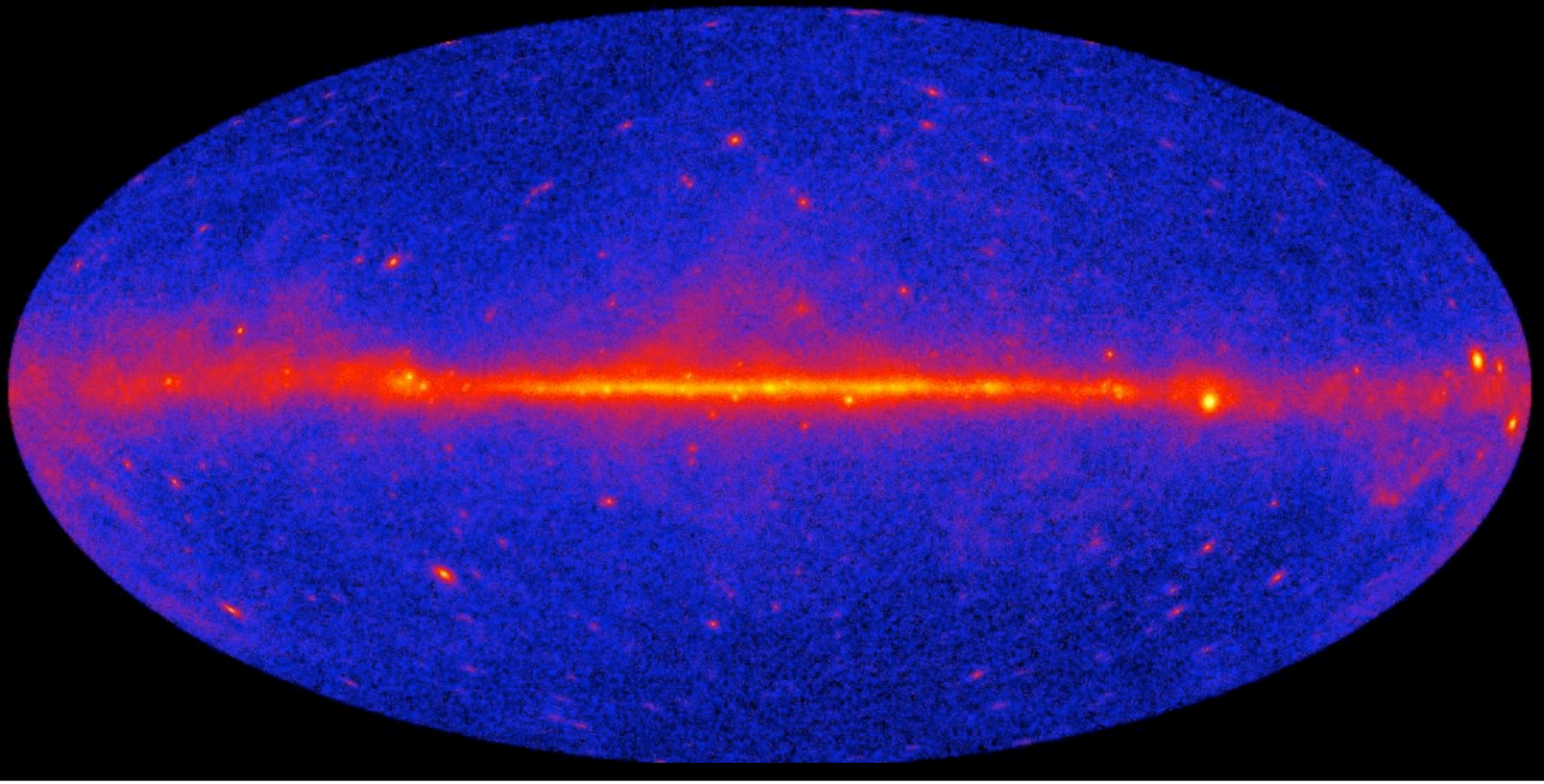



**3rd EGRET catalog**

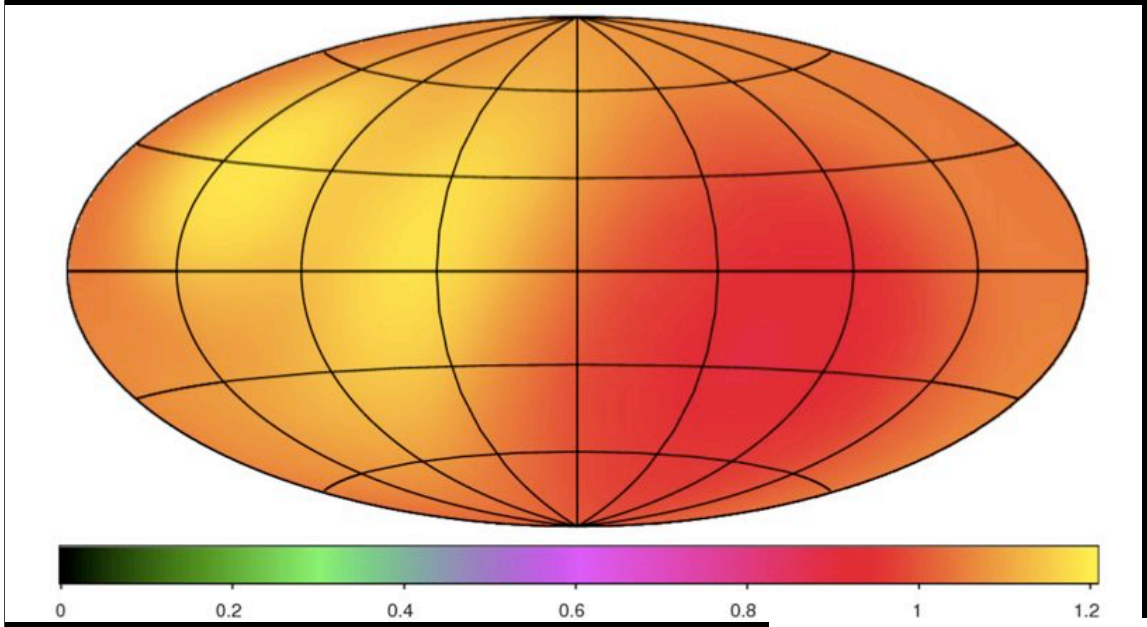
*Revised catalog (Casandjian & Grenier08): 107 unconfirmed sources!*

# The Fermi 3months sky

- Aug-Sept-Oct:~3e6 γ-rays after cuts (>100 MeV)
- Most of photons come from the Galactic diffuse
- For comparison the  EGRET sky had 1.4e6 γ-rays



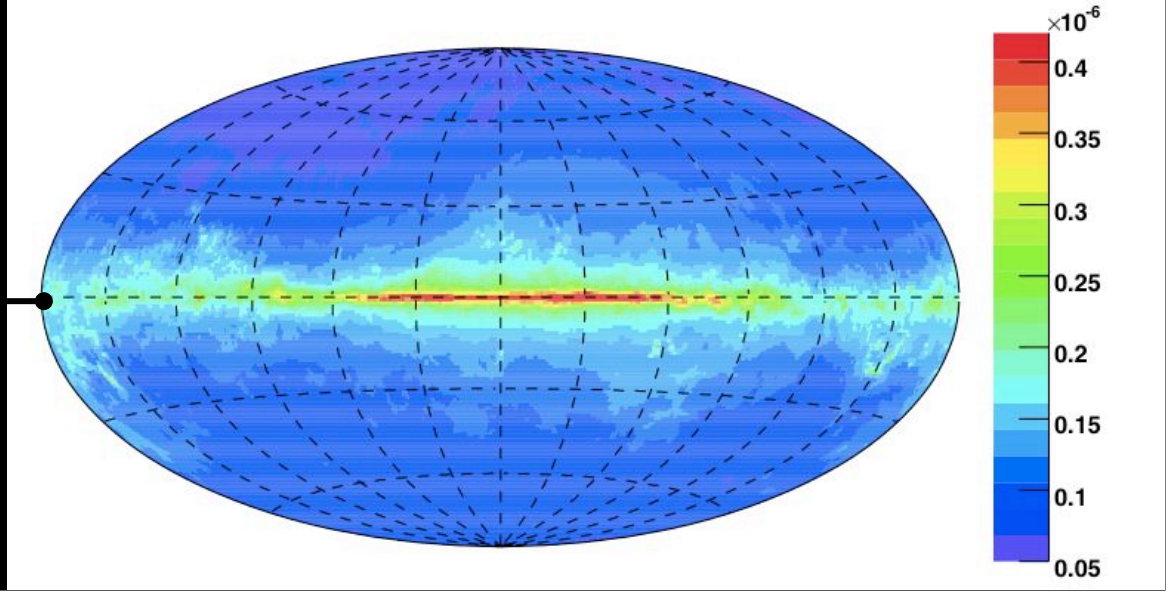
# Exposure and Sensitivity(>10σ)




Exposure uniform within 30%

It does <u>not</u> imply <u>uniform sensitivity</u>

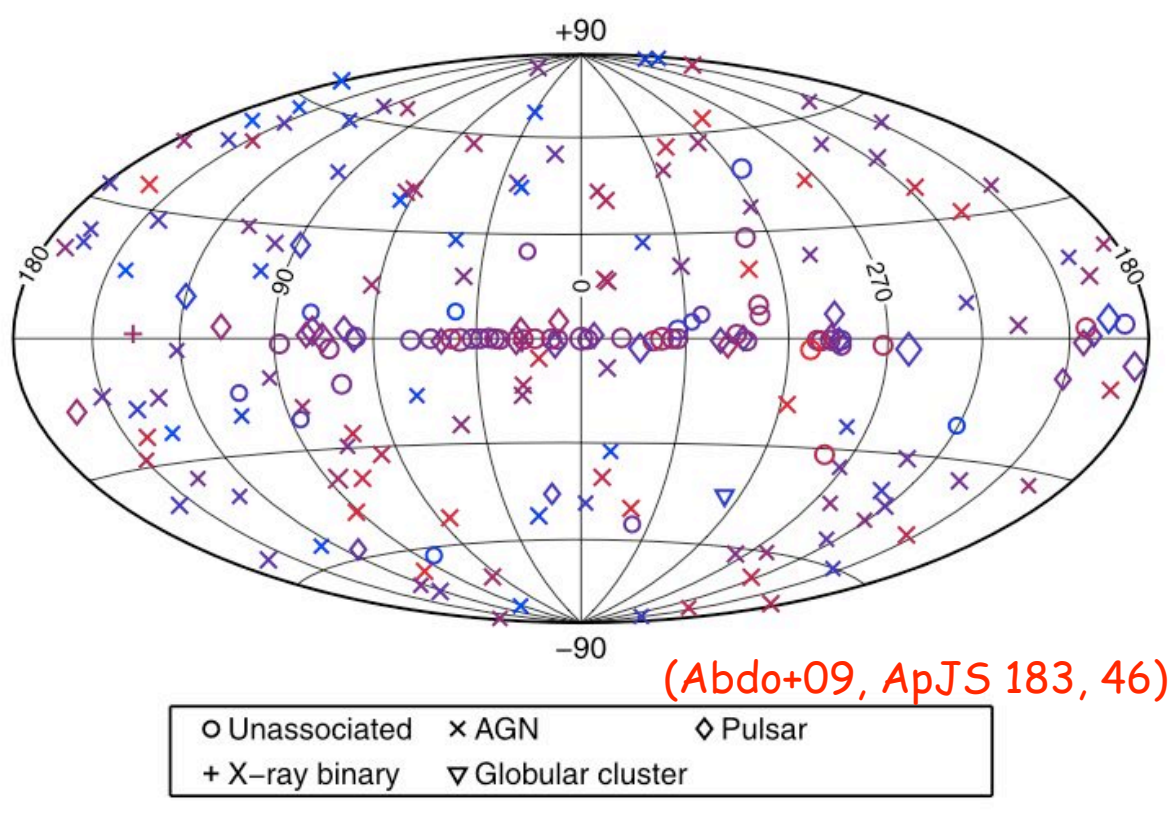
3months sensitivity to a 10σ source with $E^{-2.2}$



# Detecting γ-ray sources

- Since most of the photons come from the Gal. Diffuse: use the most reliable model of diffuse emission needed
- Create set of count maps combining front and back events
  - High-energy maps give better positions and resolutions but lack statistics
- Refine positions
- Ingest seeds to Maximum Likelihood
- Associations: statistical assessment of the likelihood that a γ-ray source is associated with a cataloged one

# The Bright Source List




| CLASS | # objects |
|---|---|
| All | 205 |
| Radio/X-ray PSR | 15 |
| LAT PSR | 14 |
| FSRQ | 62 |
| BLLAC | 46 |
| Blazar (uncert.) | 11 |
| RG | 2 |
| HMXB | 2 |
| LMC | 1 |

205 sources >10σ (EGRET had ~30)

Typical error radius (95%CL) is 12′

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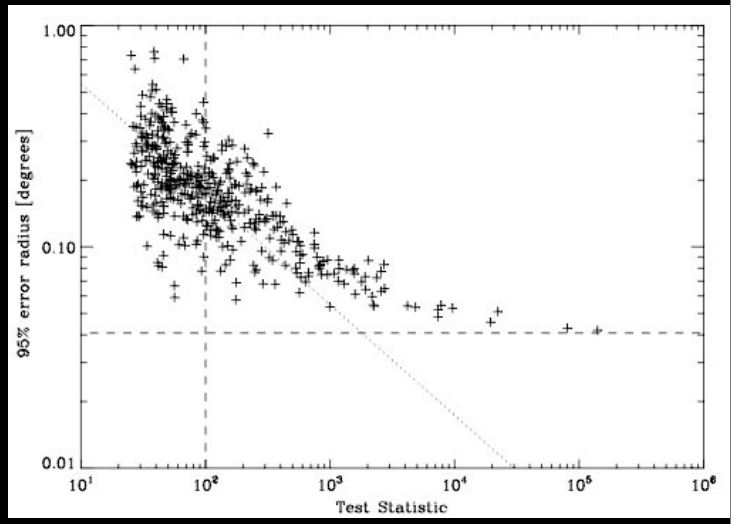
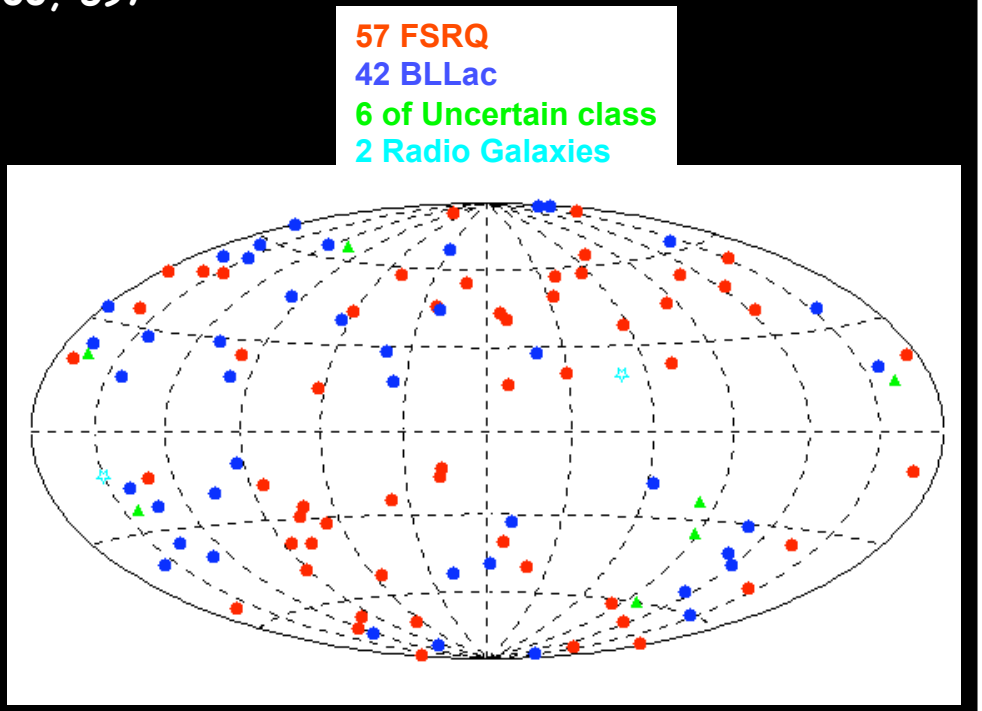
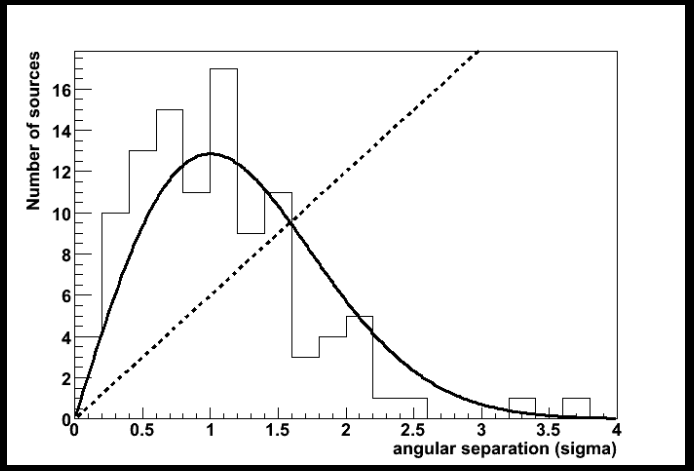


# The LAT bright AGN List (LBAS)

Abdo+09, ApJ 700, 597

- 125 non-pulsar sources at |b|>10°
- 106 high-confidence (P>90%) associations with AGNs: (LBAS)
- 10 lower-confidence associations
- FSRQs: 57
- BLLacs: 42
- Uncertain class: 5
- Radiogalaxies: Cen A, NGC1275
- 40% BLLacs (23% for EGRET)
- 7 HBLs (3+1 for EGRET)
- 5 unassociated (|b|>10°)

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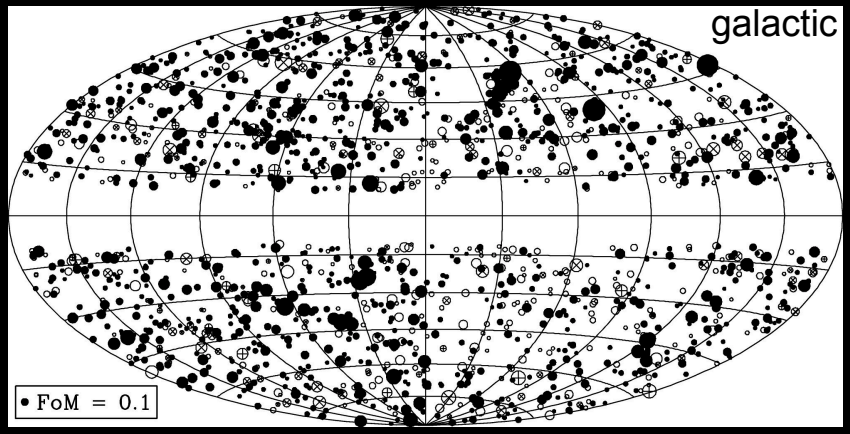
# Associations

**0FGL**: 132 sources with TS>100, |b|>10°
7 pulsars, **125 AGN candidates**

## CGRaBS

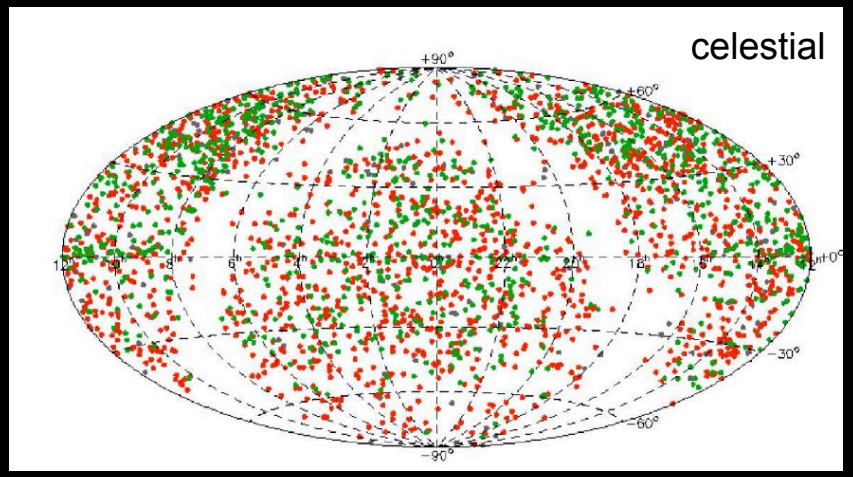
1627 radio sources from CRATES
association based on Figure-of-Merit (spatial, radio and X spectrum) established from EGRET




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

## BZCat

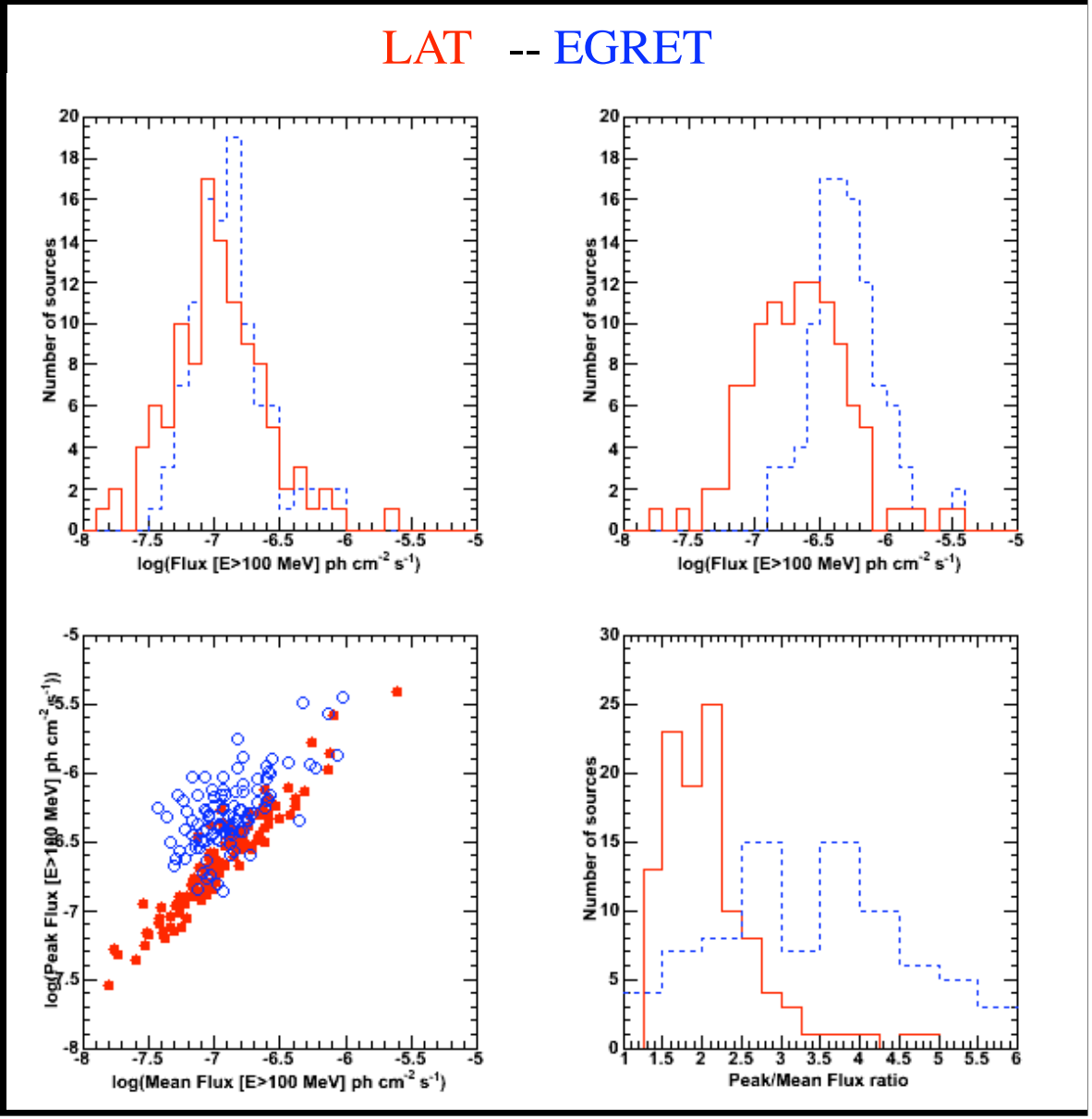
Compilation of 2500 known blazars association based on spatial coincidence (Mattox et al., 01)



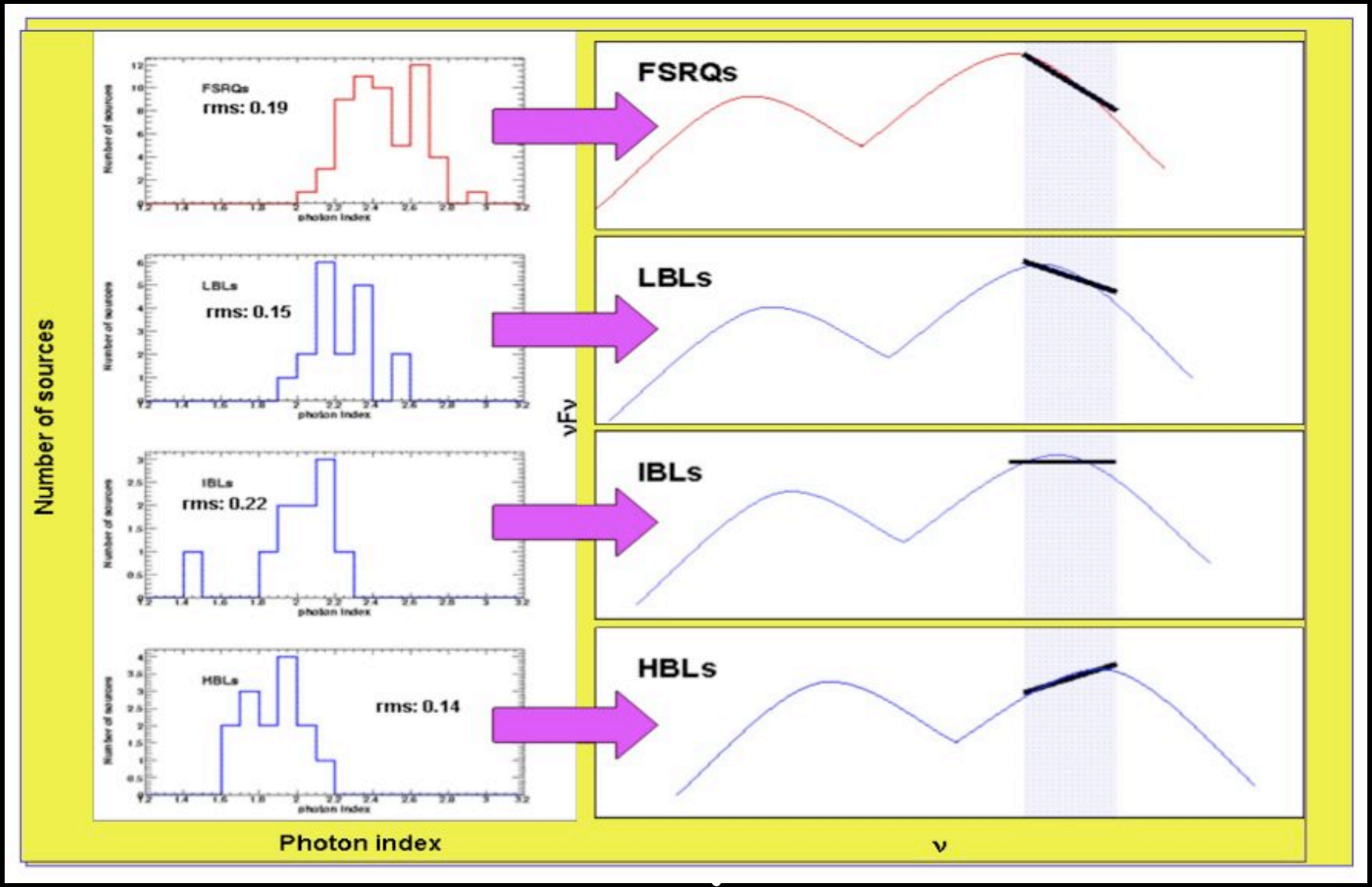

102 high-conf. (P>90%) associations
4 low-conf. (40%<P<90%) associations

# Key Properties: flux distr.

- EGRET mean flux = <1234> VP flux
- EGRET peak flux = max 2week flux
- LAT mean flux = average over 3months
- LAT peak flux over 1week

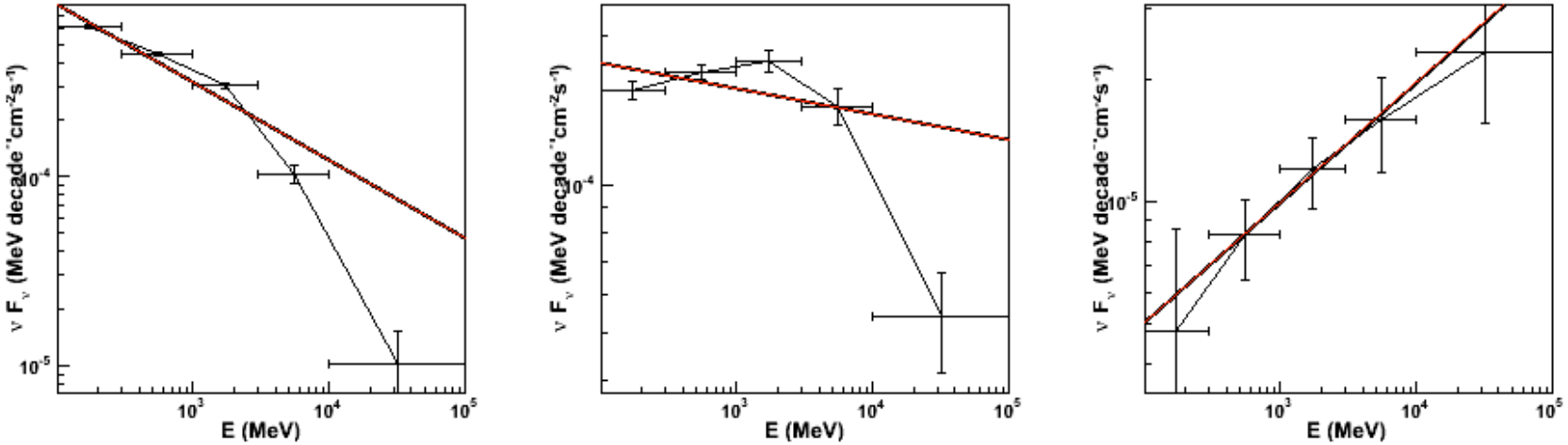


# Key Properties: photon indices



# More on spectra

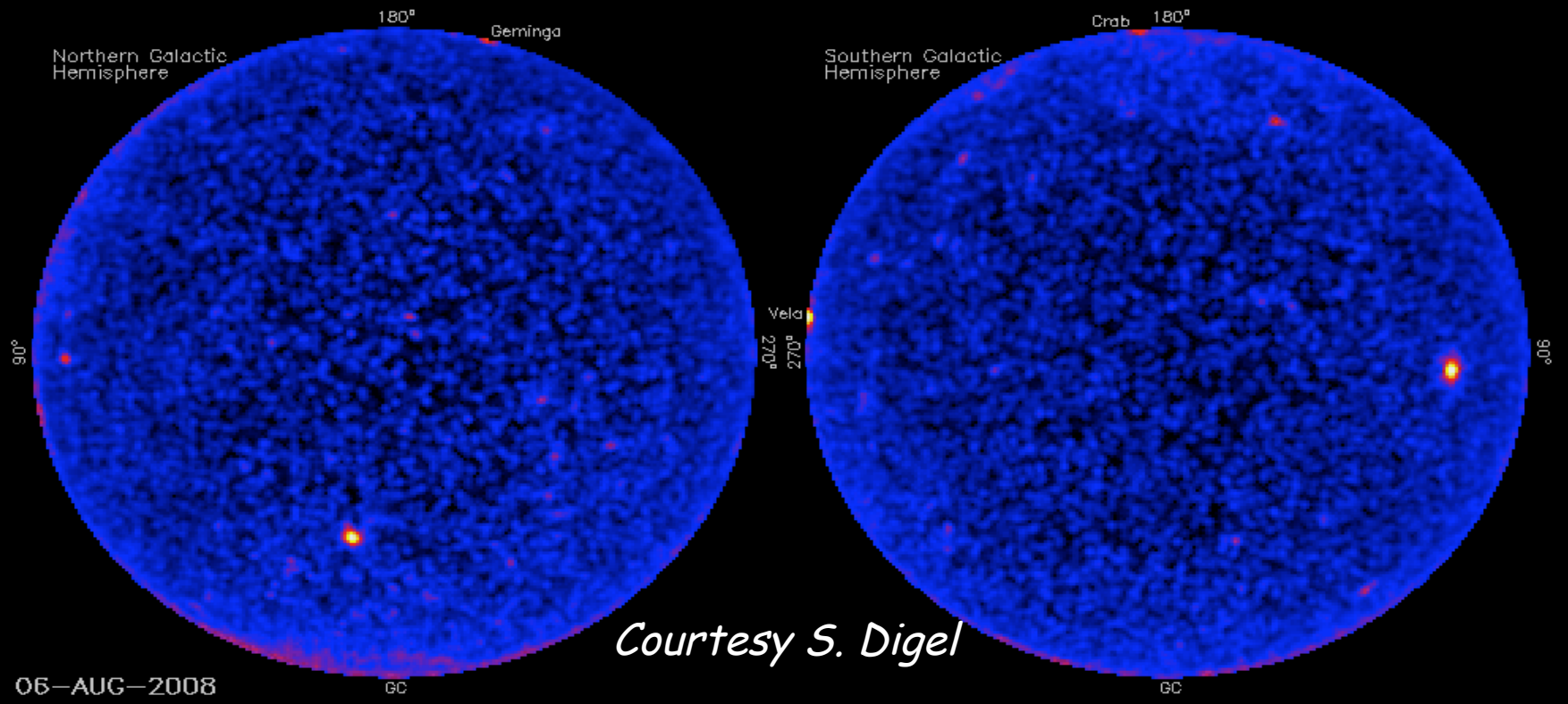
**3C454.3 (FSRQ)** **AO 0235+165 (Int. BL)** **Mkn501 (HBL)**




*Significant departures from pure power-law distributions for bright blazars!*

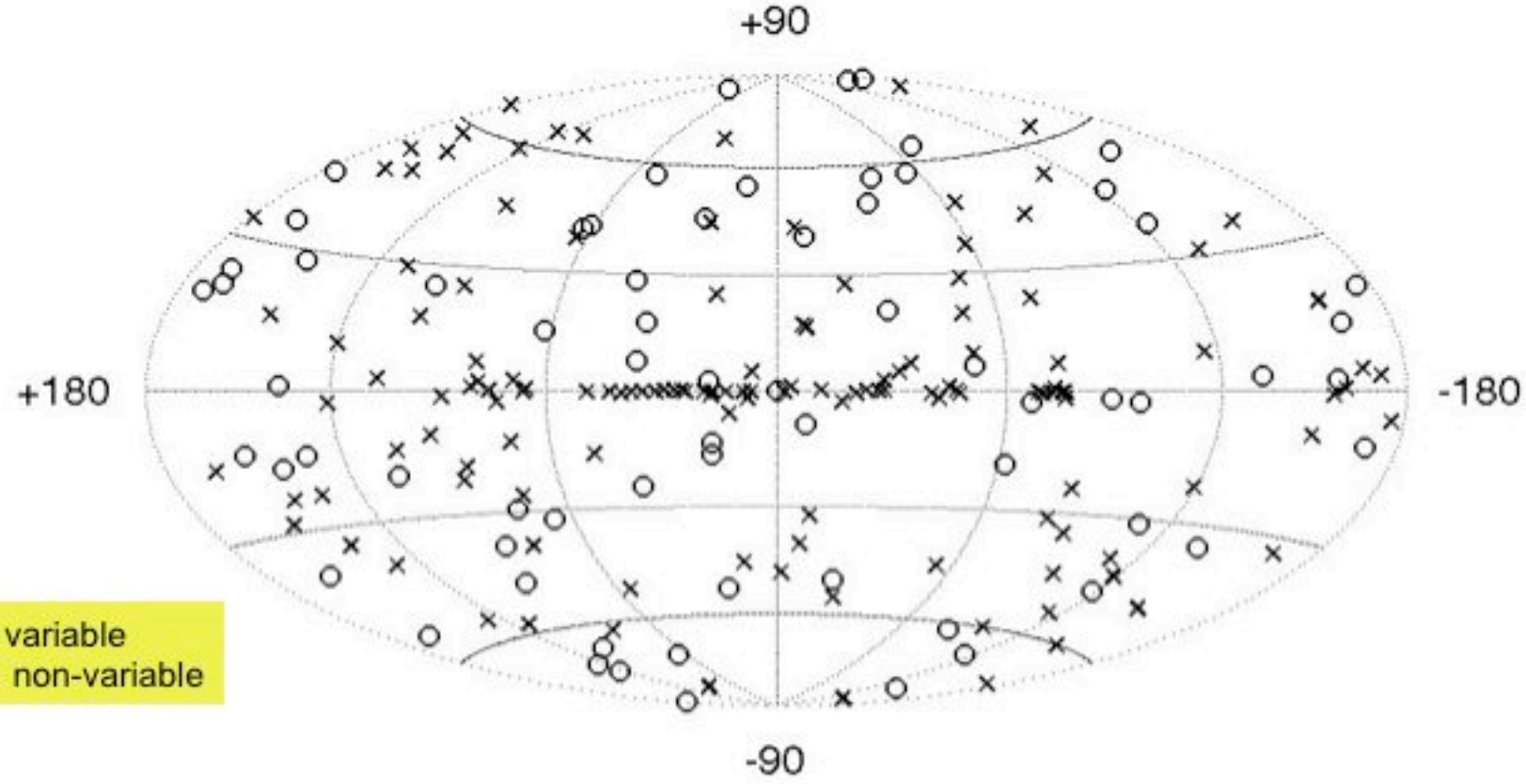
*FSRQs seem to have the IC peak at E< 1GeV*

# Time Dimension



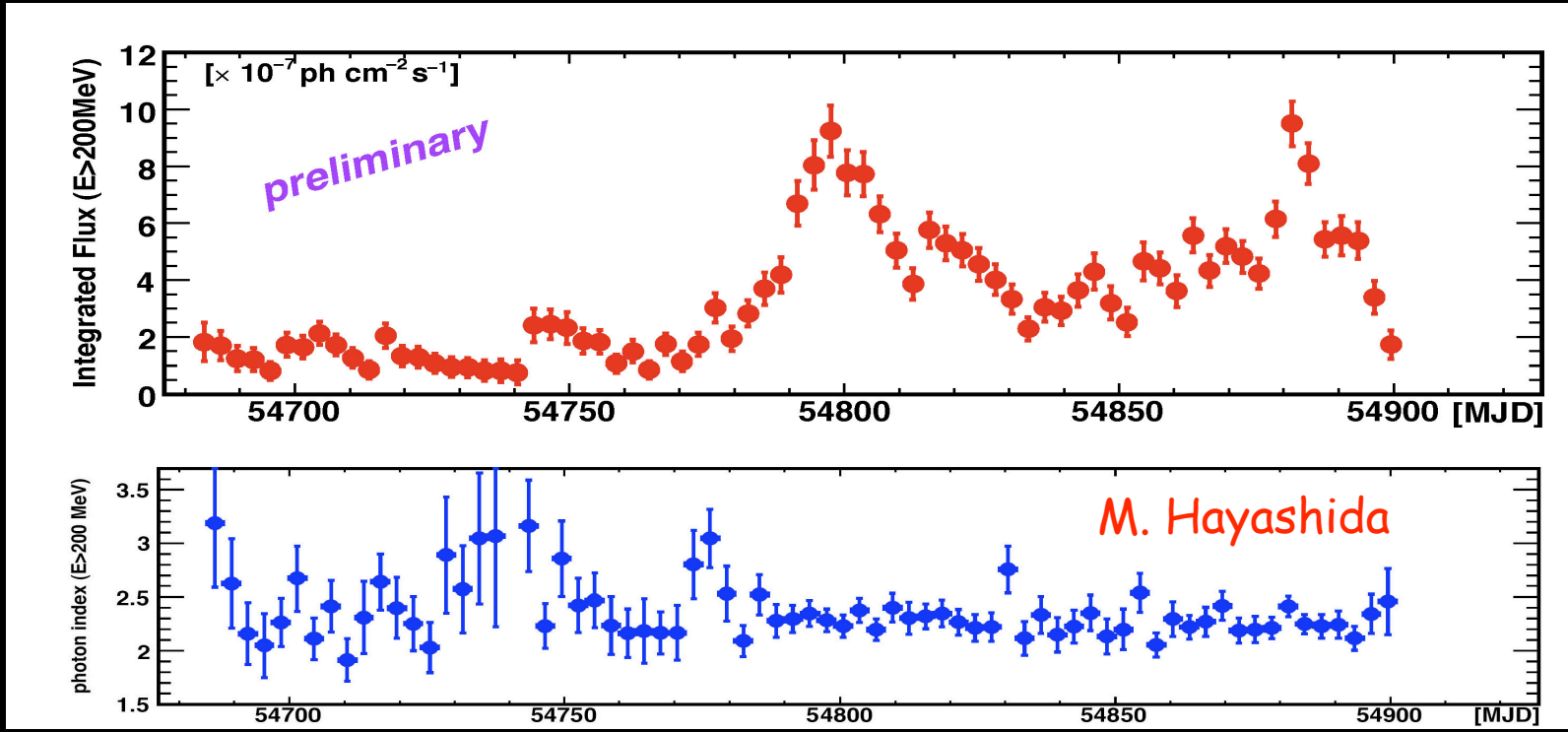

*Courtesy S. Digel*

# Variability




- **Based on 1 week time scales**
- **68 show variability with probability > 99%** (Most are blazars)
- **Isotropic distribution ⇒ blazars**

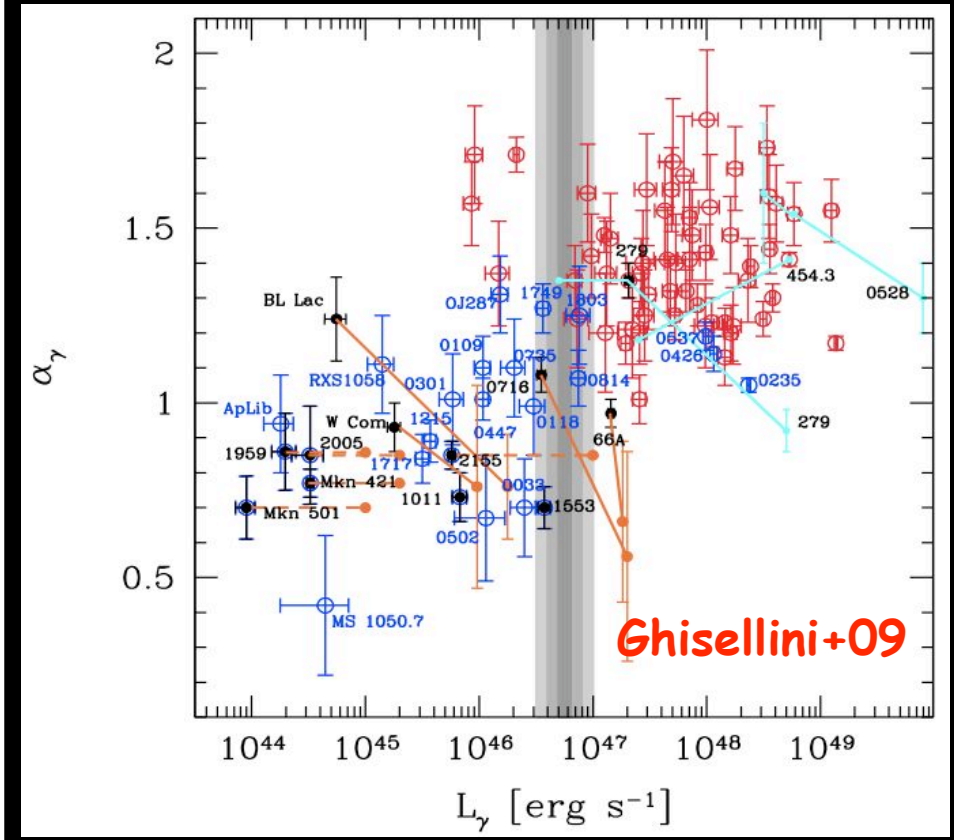
# Spectral variability ?

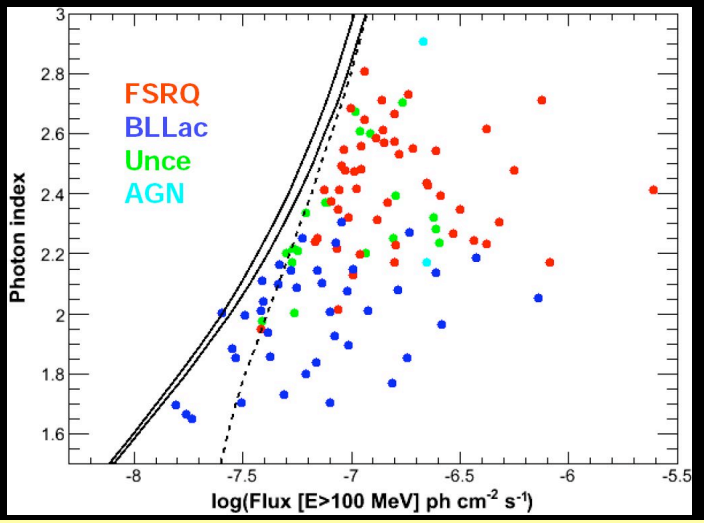



Photon index 'constant' with flux irrespective of source class

Weak indication for harder when brighter behaviour

# Luminosity vs Index




BL Lacs and FSRQs separated in the L-$\alpha$ plane.

$L_{div}$ corresponds to accretion rate of 0.01Edd.

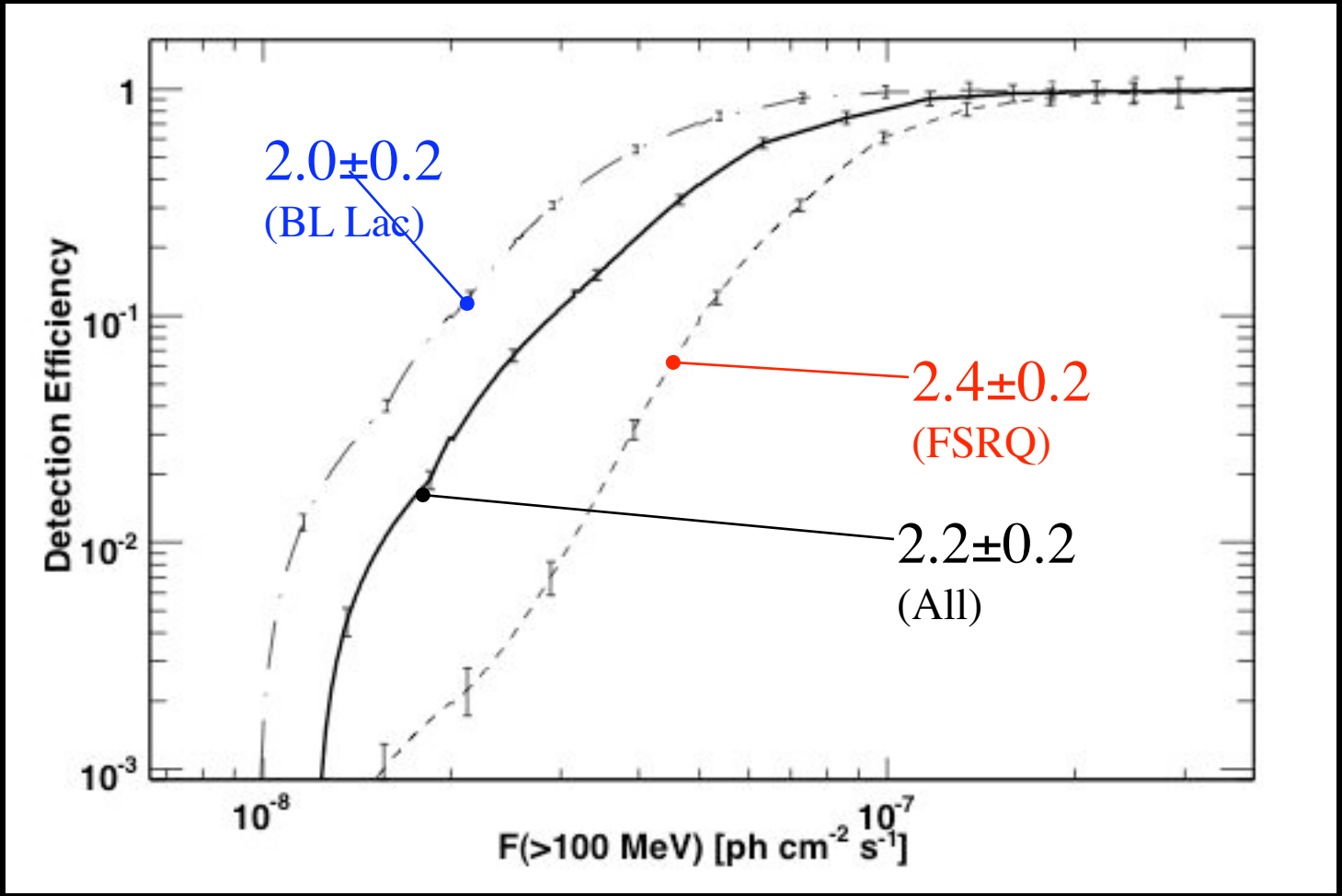
BL Lac have low accretion rates, optically thin acc. flow

FSRQs have high accretion rates, thick SS disk and BLR

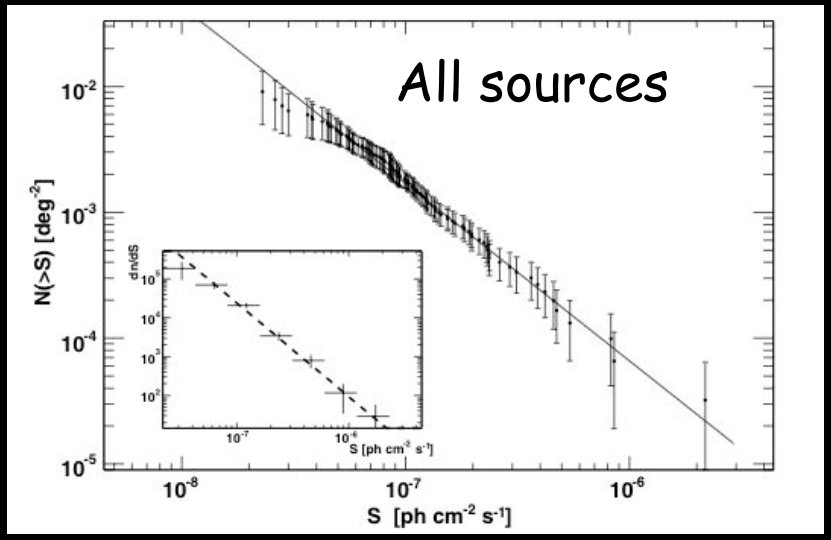
# How to address biases

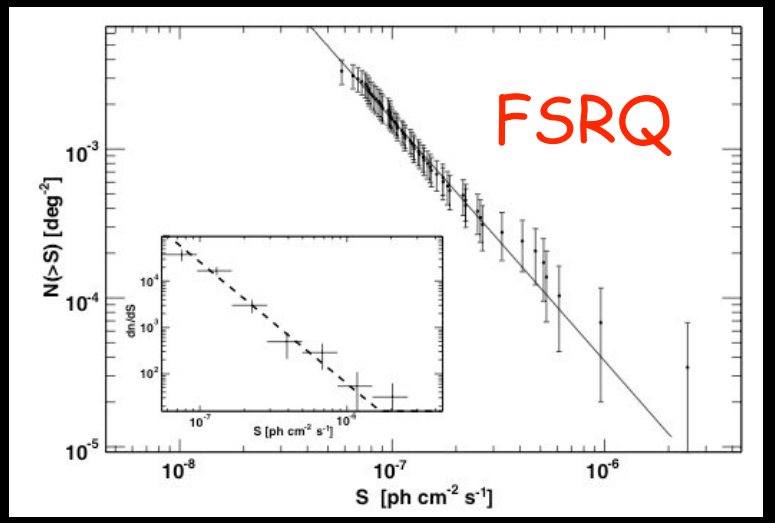
- Simulate your intrinsic source population
  - Diffuse emissions
  - Random source population drawn from a logN-logS distribution
  - Perform detection stage (time consuming)
  - Associate output sources to input sources
  - Repeat N times
- Possibility to learn about:
  - Pos. accuracy, Eddington bias, Malmquist bias

# LAT detection efficiency (3m, 10σ)



# Log N - Log S

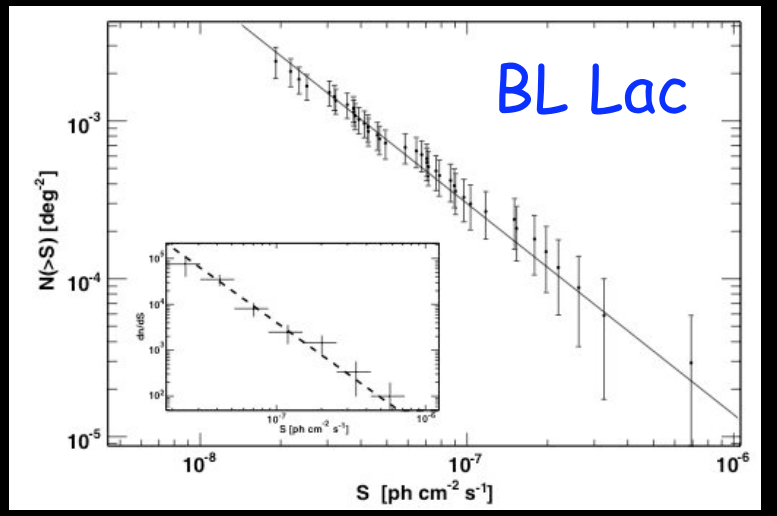



LAT resolves ~7% of the LAT EDB

No significant deviation from Euclidean

| Blazar class | slope |
|---|---|
| All | 2.50±0.12 |
| FSRQs | 2.55 ±0.12 |
| BLLacs | 2.32 ±0.15 |

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# Test for Evolution: $\langle V/V_{max} \rangle$

$\langle V/V_{max} \rangle$: ratio between the comoving volume within which the source was detected and the maximum volume available for its detection

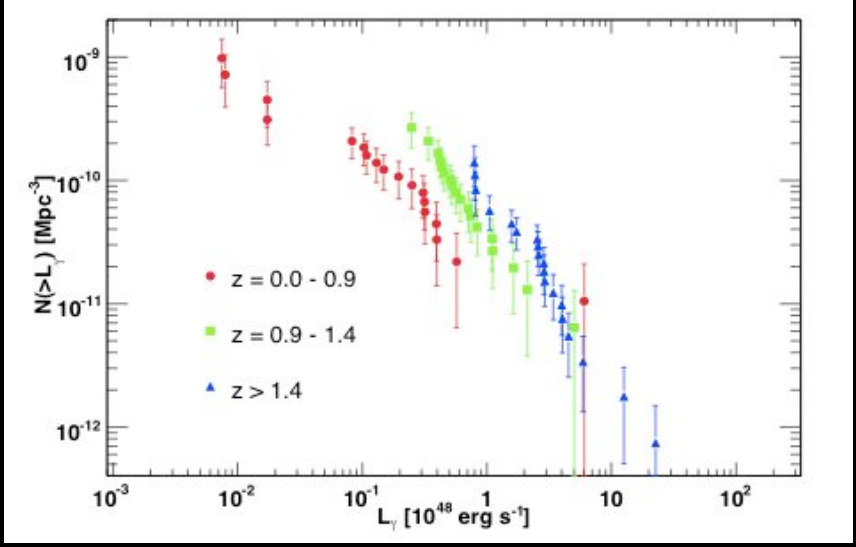
Population uniformly distributed in Euclidian space, non evolving:
$\langle V/V_{max} \rangle \sim 0.5$

| Sample | #objects | $\langle V/V_{max} \rangle$ |
|---|---|---|
| FSRQs | 57 | 0.645±0.043 |
| BLLacs | 42 | 0.473±0.046 |
| All with z>0 | 92 | 0.512±0.031 |

Positive evolution for FSRQs (more FSRQs in the past)
Compatible with no evolution for BLLacs

# Blazar Evolution in LAT

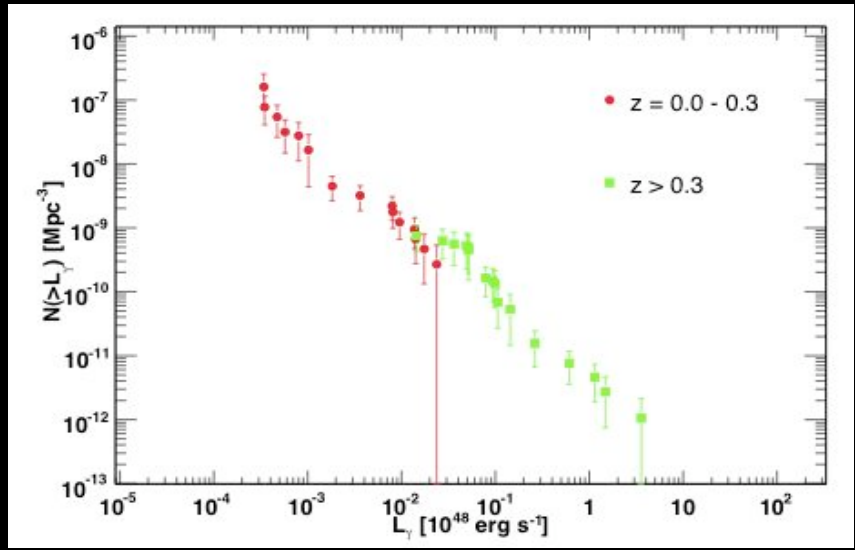
## FSRQs (59)




Strong Positive Evolution
$V/V_m=0.645\pm0.043$

Power-law slopes: ~2.5

## BL Lacs (29)

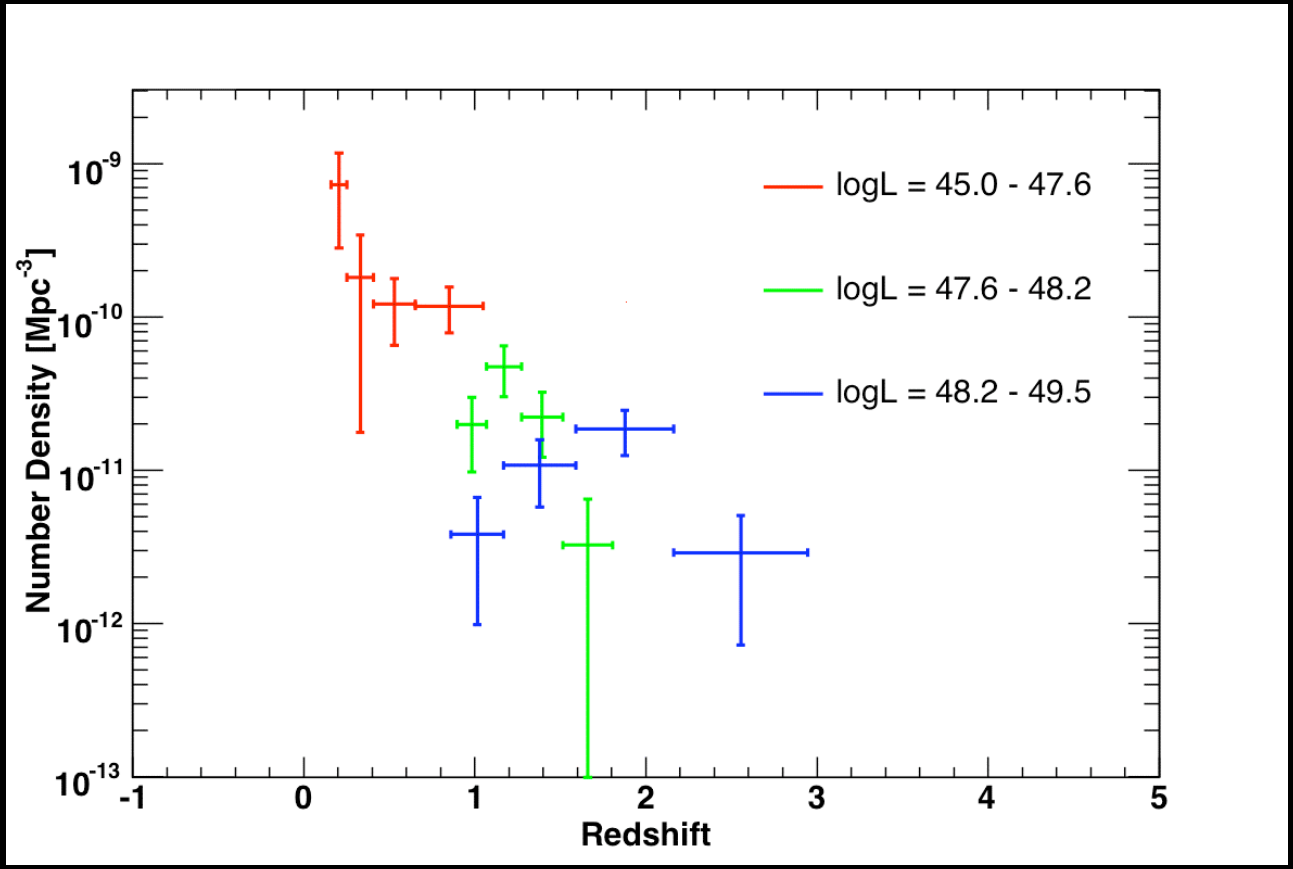



No significant Evolution
$V/V_m=0.422\pm0.055$

<u>But: 13/42 BL have no z</u>

Power-law slopes: ~2.2

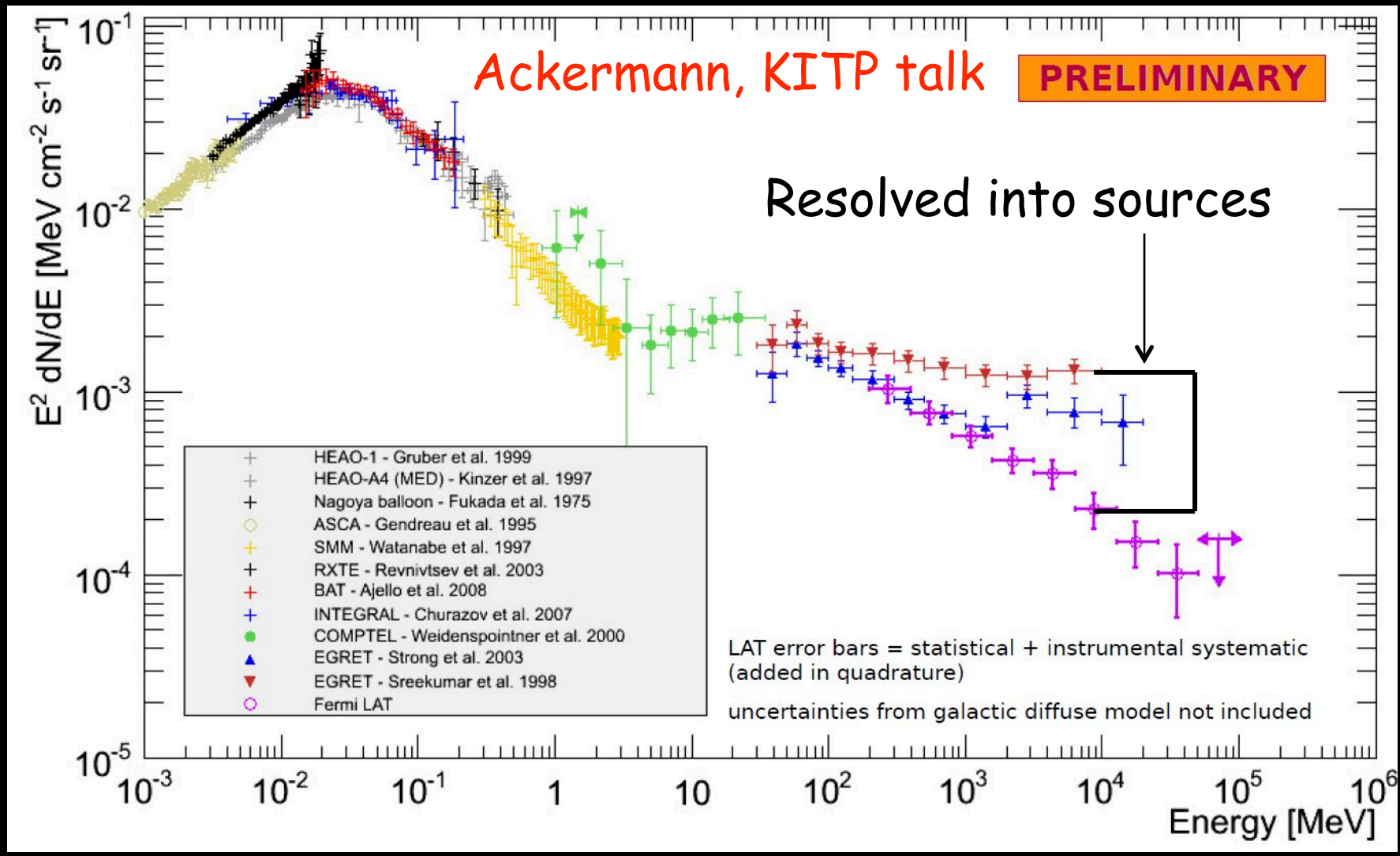
# Redshift cut-off




Density of luminous blazars peaks at z ~ 1.7

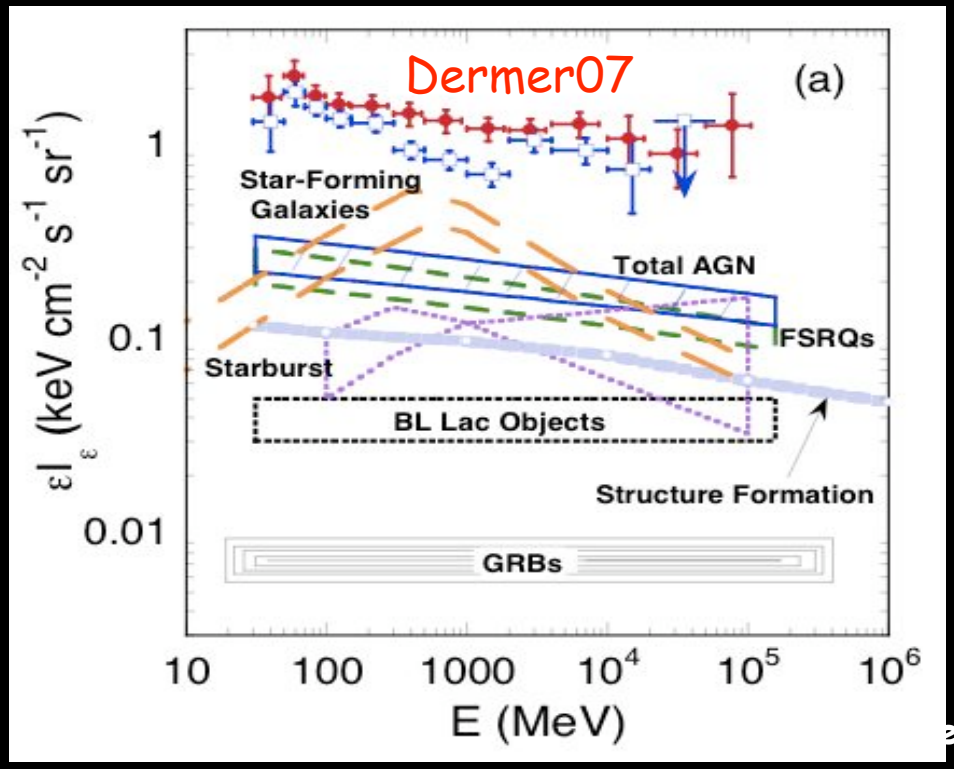
Similar to radio-selected blaz. (Dunlop&Peacock90, Wall+05)

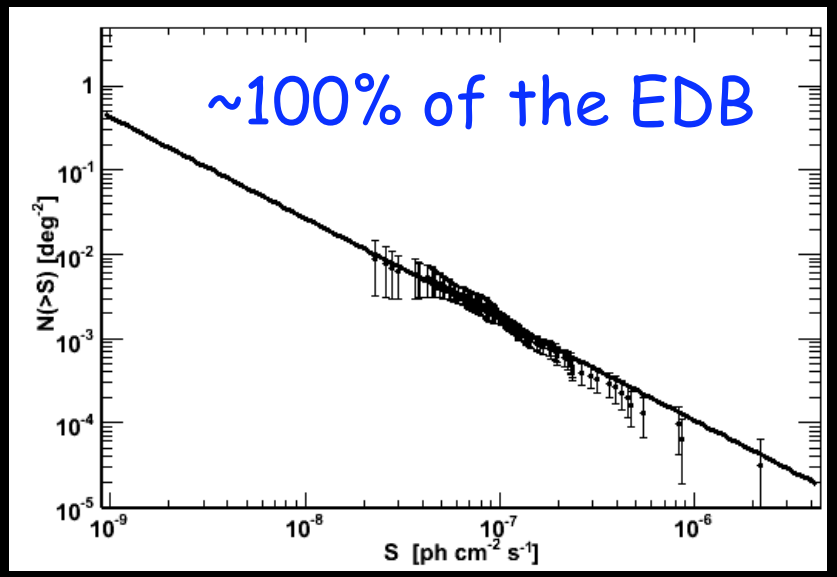
# Contribution to the LAT EDB

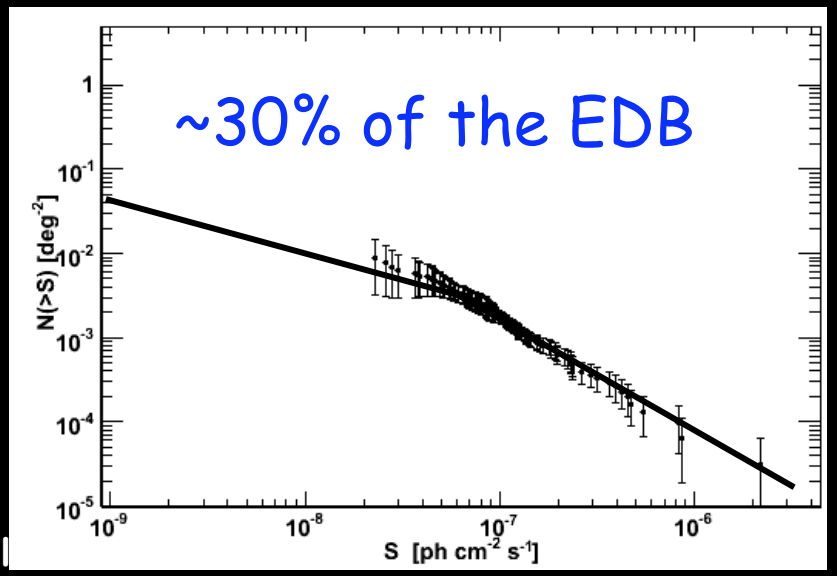


# Contribution to the LAT EDB

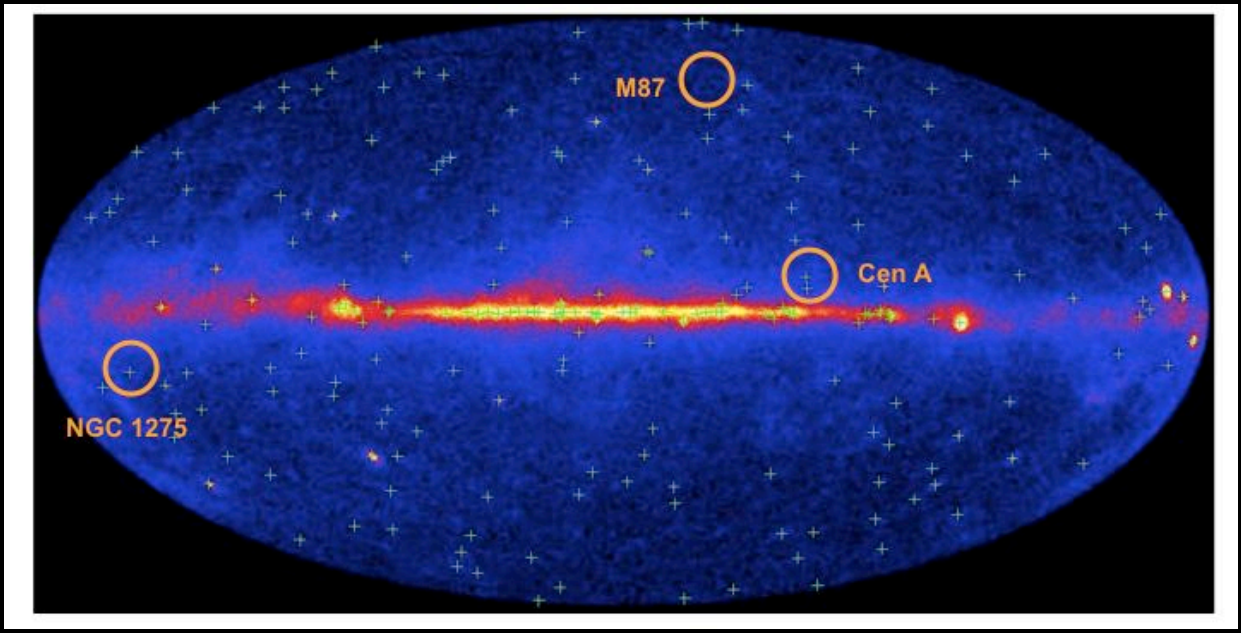
- Assess contribution of blazars first by investigating the behaviour of the logN-logS at low fluxes



# Other Pops.: Radio Galaxies

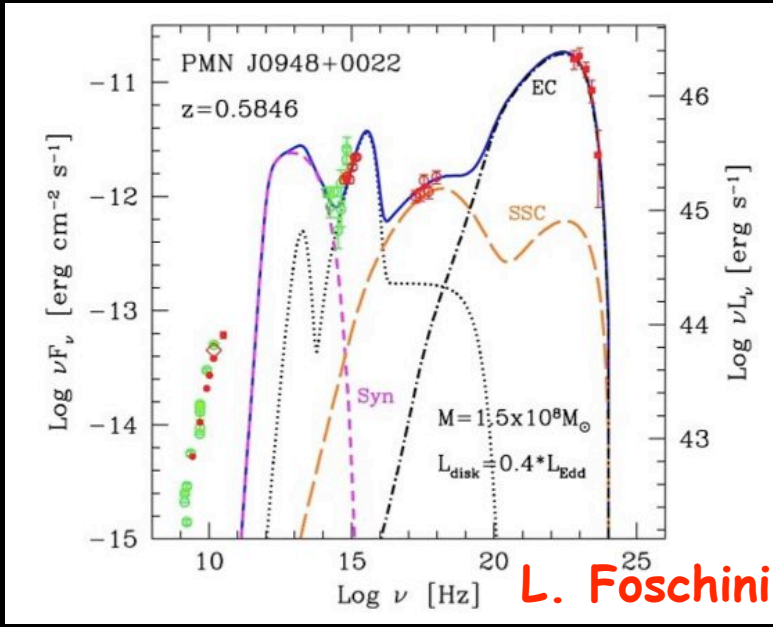



Contacts:
Kataoka
Cheung
Finke

- Misaligned jets: low $L_\gamma$~1e44 erg/s, but more numerous than blazars
- Must be detected in large numbers to account for a substantial fraction of the EDB

# Other Pops.: RL-NLSy1

- Optical: narrow permitted lines FWHM($H_\beta$)<2000km/s, 10% are RL (e.g. Komossa+06)
- Radio: emission is strongly variable with flat spectrum -> suggests doppler boosting confirmed by LAT
- GeV: resemble low-power FSRQs

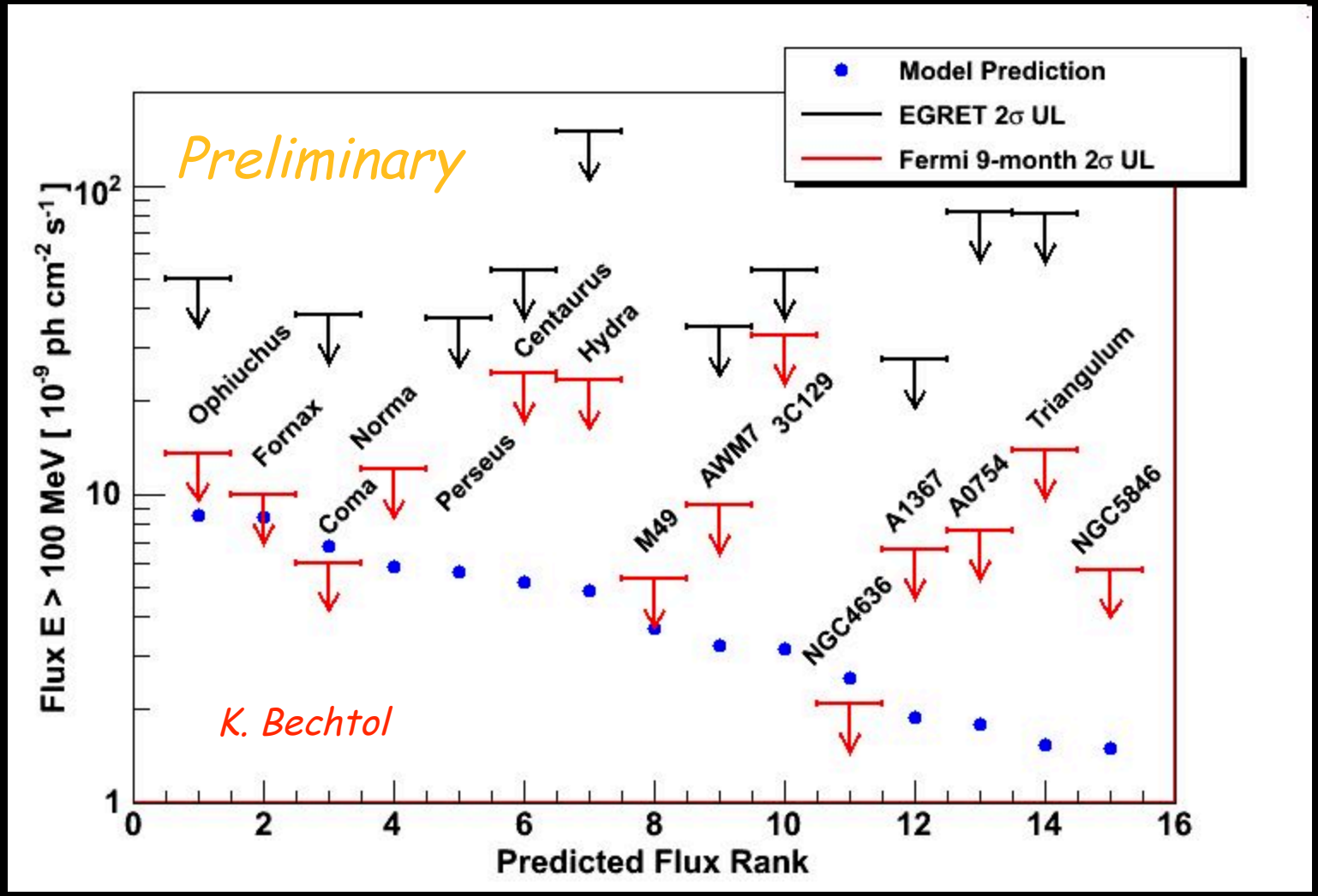



L. Foschini

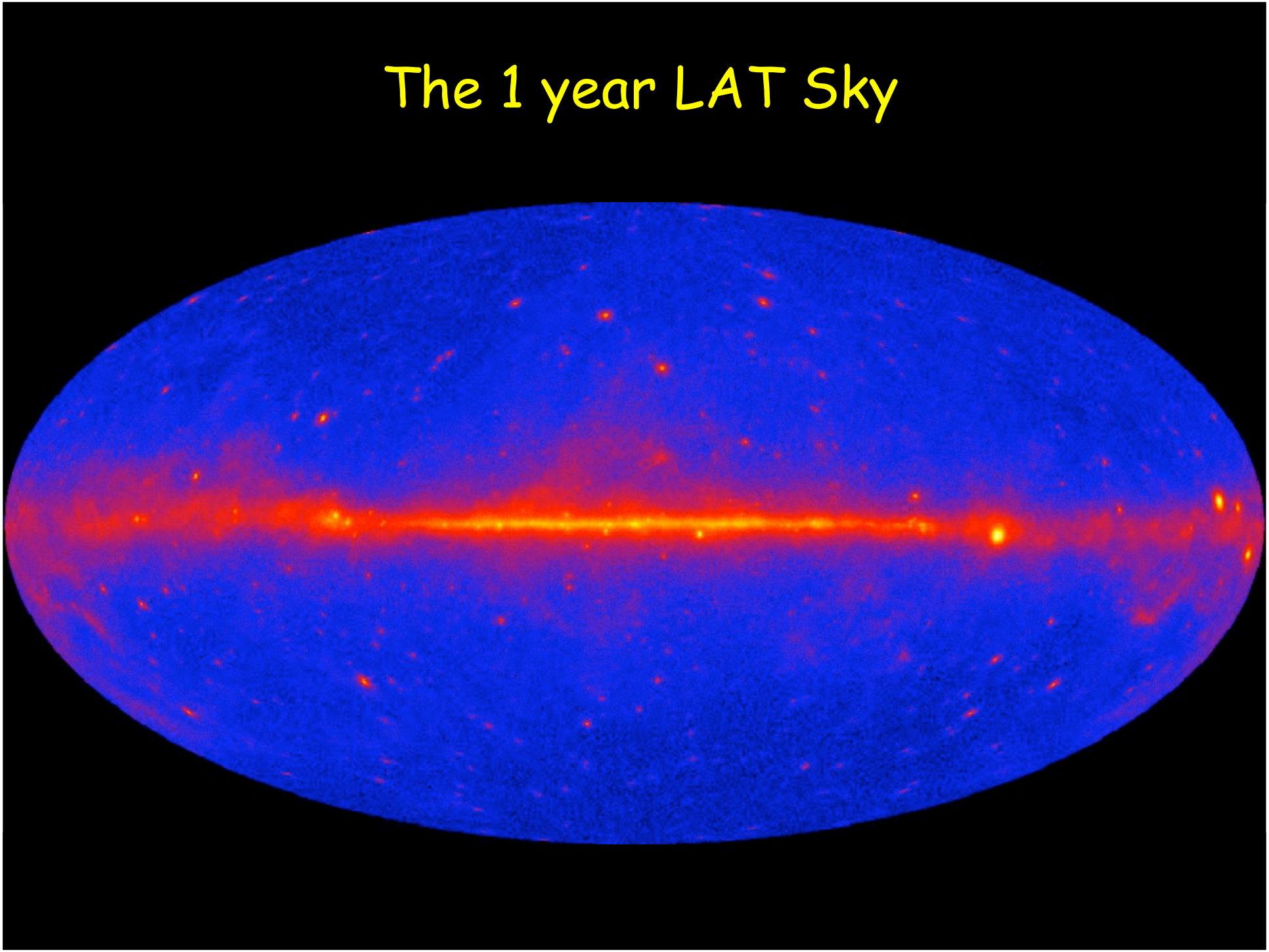
Very high accretion rates (~0.8Edd) and small (1e7) BH masses

The host is a spiral G.

# Other Pops.: Clusters of Galaxies



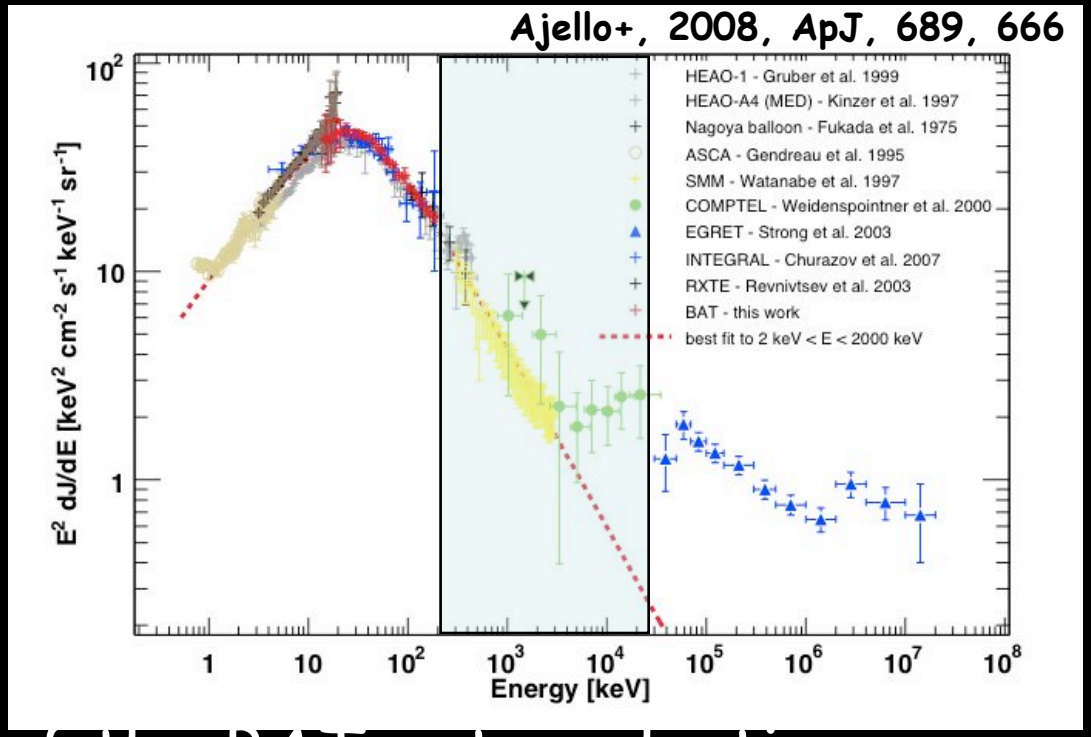
# The 1 year LAT Sky



# Perspective for the 1year survey

- With more than 1000 sources:
  - Determine logN-logS and derive the contribution of all point-like sources
  - Determine logN-logS for all sources classes (depending on statistics/associations/completeness)
  - Possibly make a logN-logS in different bins of Energy
  - Make Luminosity function of FSRQs and BL Lacs
  - Test isotropy of sources (?)

# Studying blazars at hard X-rays




## Motivation:

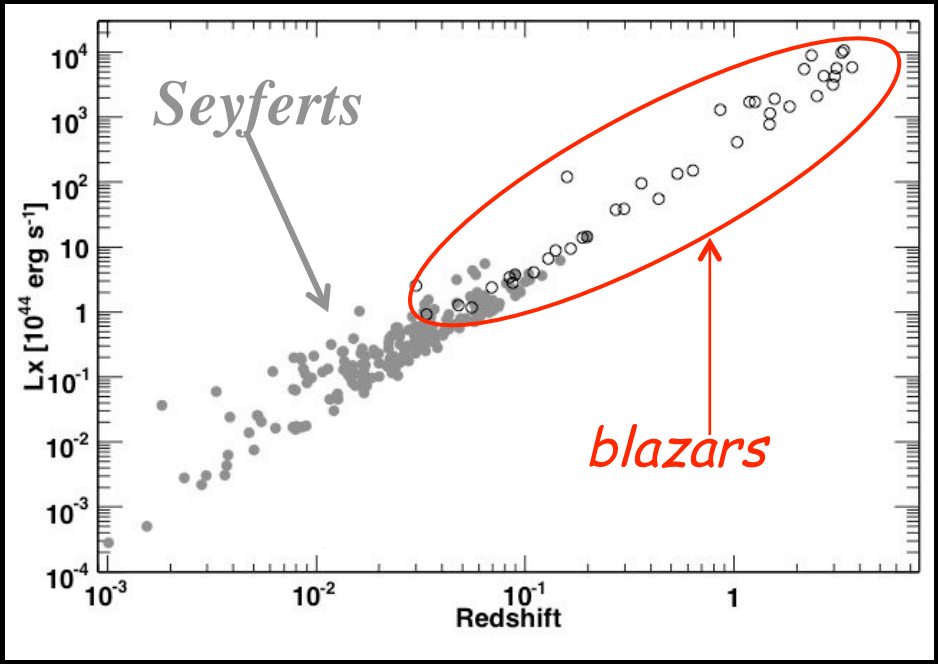
- Blazars are >15% of the BAT extragalactic sources
- MeV background unexplained
- Evolution of blazars undetermined

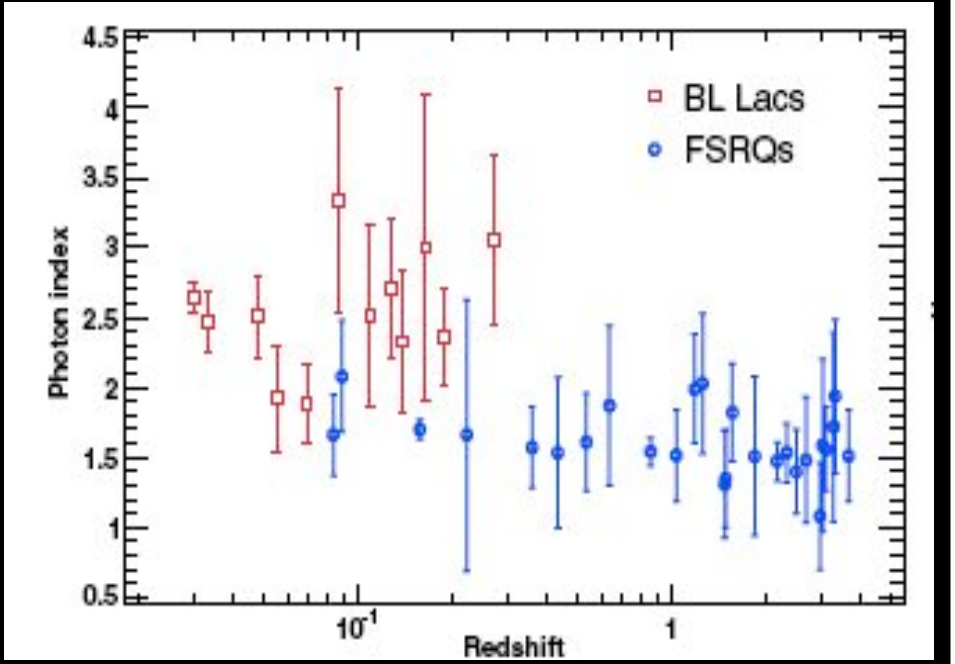
M. Ajello

- Light DM particle (Ahn&Komatsu05)
- Nuclear decays from SN Ia (Clayton & Ward75)
- NT $e^-$ in AGN coronae (Inoue+08)

# The BAT 3yr Sample

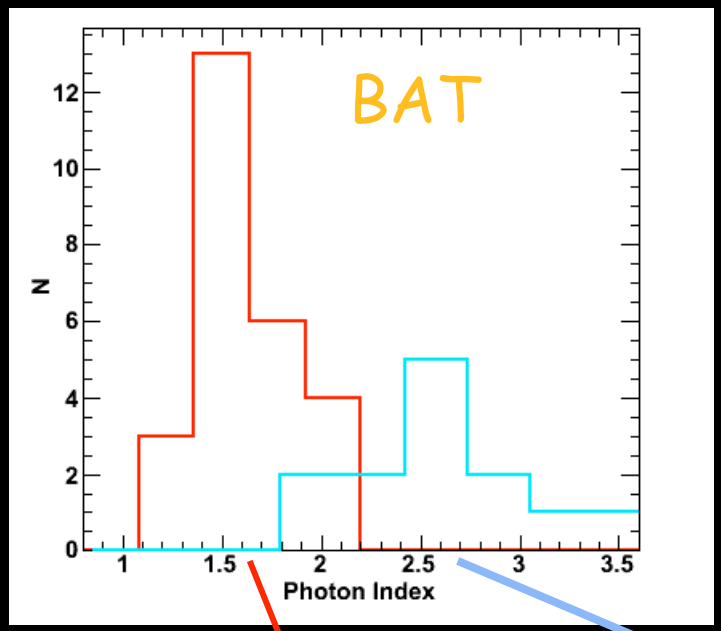
**Ajello+09, ApJ 699, 603**

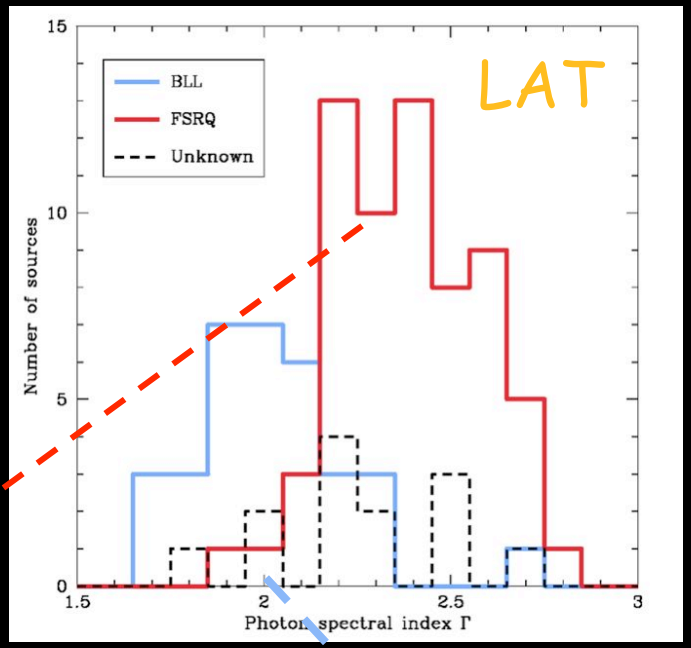


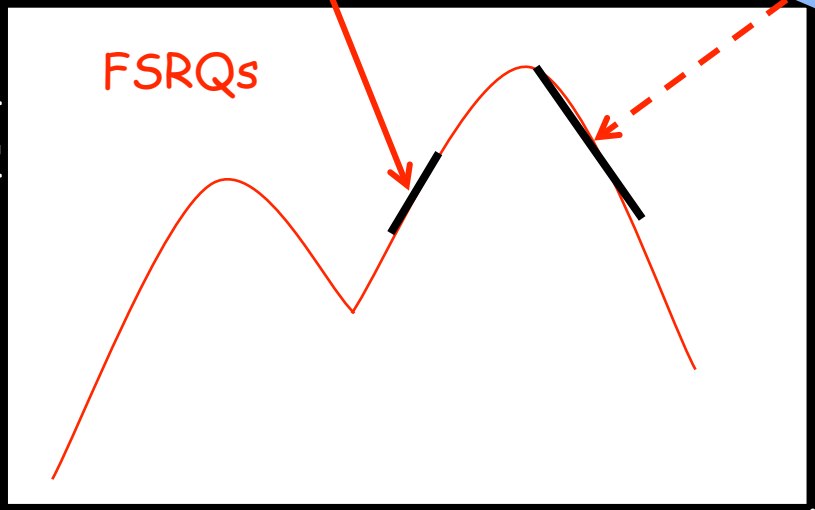



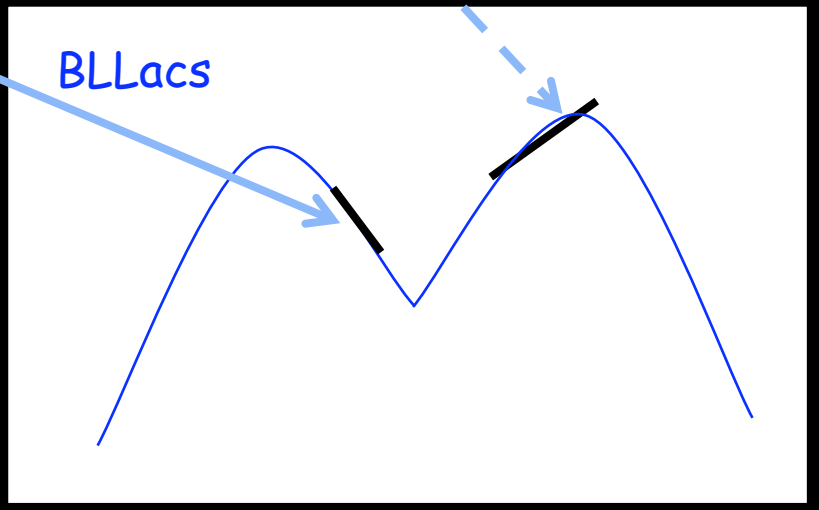

- 38 blazars (26 FSRQs, 12 BL Lacs) detected up to z~4
- 9 FSRQs and 3 BL Lacs in common with EGRET/LAT
- No blazars at low $L_X$ and low redshift

# Some Key Properties



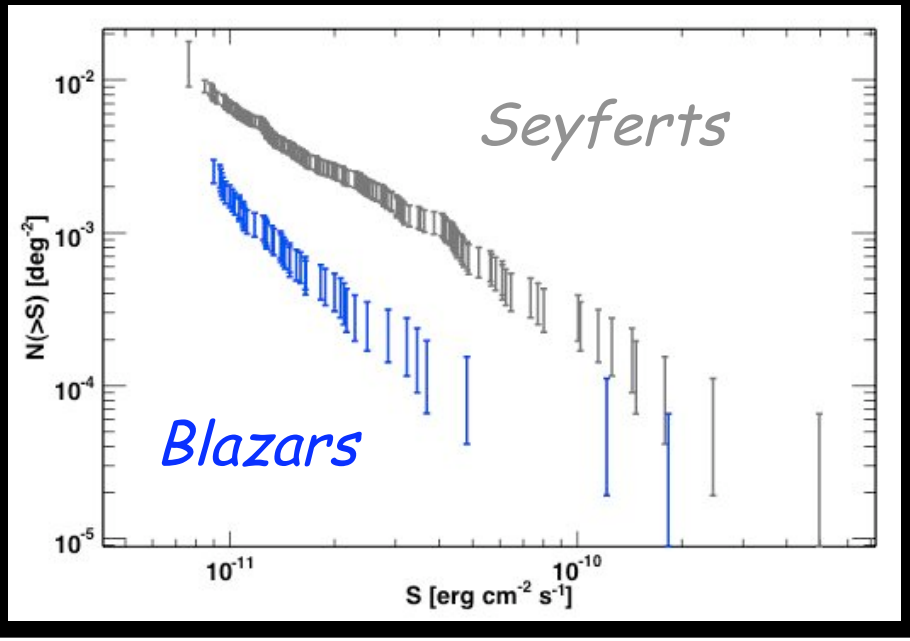



# Test of Evolution

- Luminosity function needed to assess the contribution of a source class to the diffuse background

| Sample | $\langle V/V_{MAX} \rangle$ | $\beta^a$ |
|---|---|---|
| Seyferts | 0.509 ± 0.021 | 1.496 ± 0.073 |
| BLAZARs | 0.666 ± 0.045 | 1.932 ± 0.206 |
| FSRQs | 0.728 ± 0.056 | 2.077 ± 0.269 |
| BL Lac objects | 0.576 ± 0.083 | 1.694 ± 0.316 |




Aje

1. Blazars evolve positively at ~3σ
2. No significant difference between the 2 sub-classes
3. Seyferts 'do not' evolve

# Best-fit XLF for entire population

## Best Fit Model:

PLE with a redshift cutoff coupled to a local double power law XLF

$$\Phi(L_X, z=0) = \frac{dN}{dL_X} = \frac{A}{\ln(10) L_X} \left[ \left( \frac{L_X}{L_*} \right)^{\gamma_1} + \left( \frac{L_X}{L_*} \right)^{\gamma_2} \right]^{-1},$$

$$e(z) = (1+z)^{k+\gamma z}. \qquad \Phi(L_X(z), z) = \Phi(L_X / e(z), z = 0),$$

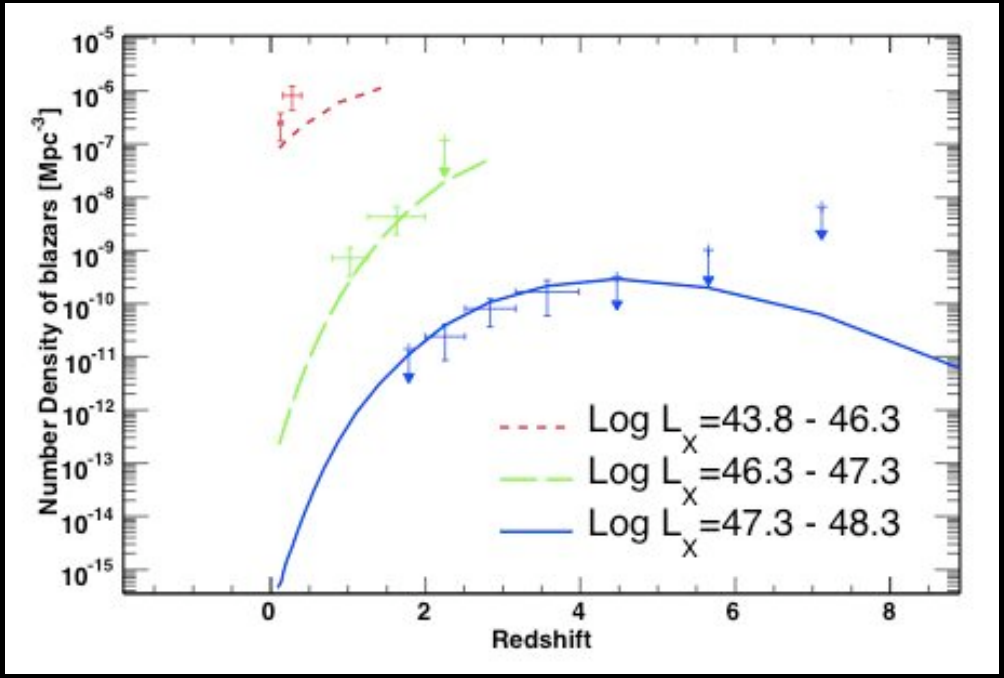
## Parameters:

$\gamma_1$=-0.87±1.31 <--beaming?

$\gamma_2$= 2.73±0.38 (Urry&Schafer84)

k= 3.45 ±0.44

$\gamma$=-0.25 ±0.07 <--3$\sigma$



# Separating the populations

## FSRQs (26)

Best fit model:

PLE: k=3.67, $\gamma$=-0.30

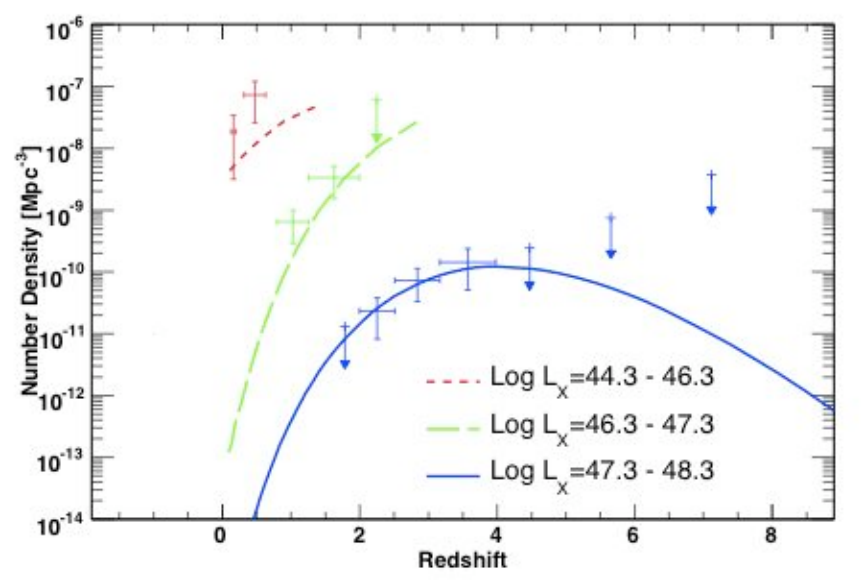
Local XLF slope: 2.49 ±0.37

## BL Lacs (12)

Best fit model:

PLE: k=-0.8±2.4 !!

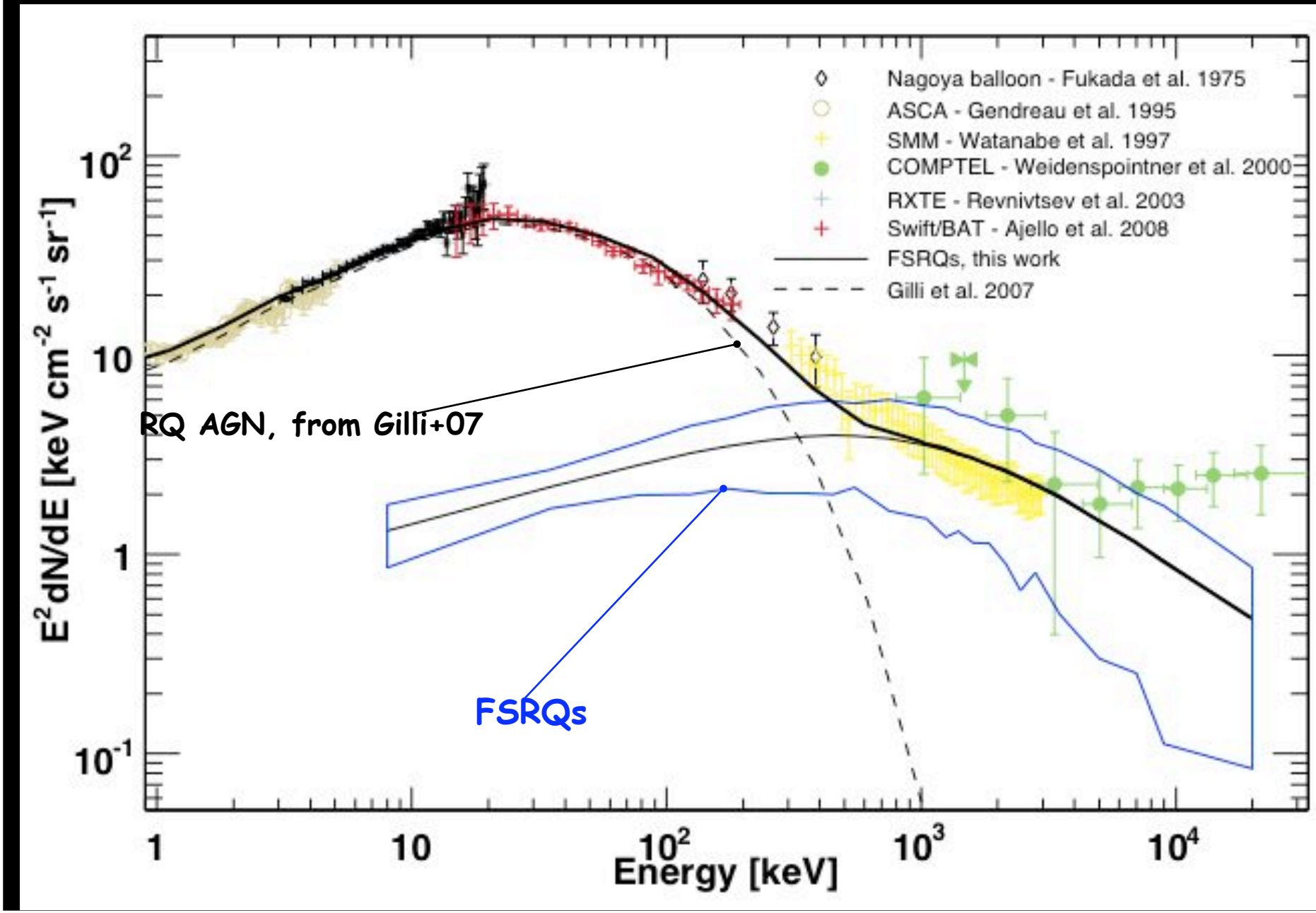
Local XLF slope: 2.61 ±0.36




Claim of negative (Rector+00, Beckmann+03) or no (Caccianiga+02, Padovani+07) evolution not confirmed/denied

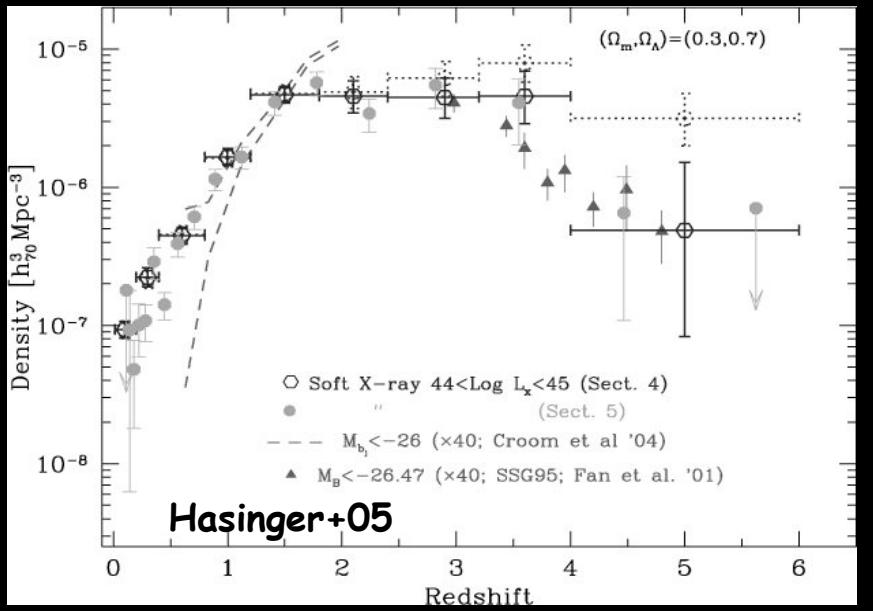
BL Lacs 'produce' <1% CXB

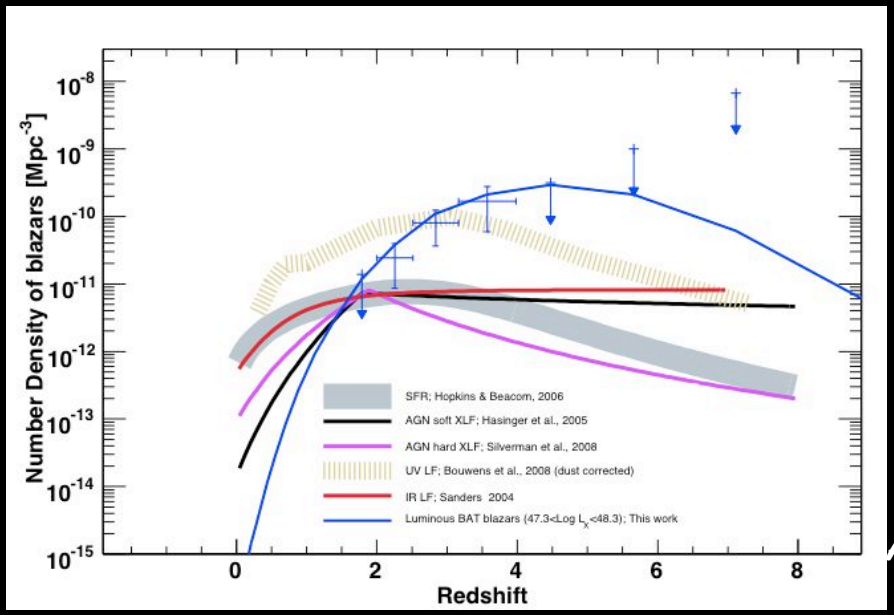
# The MeV Background



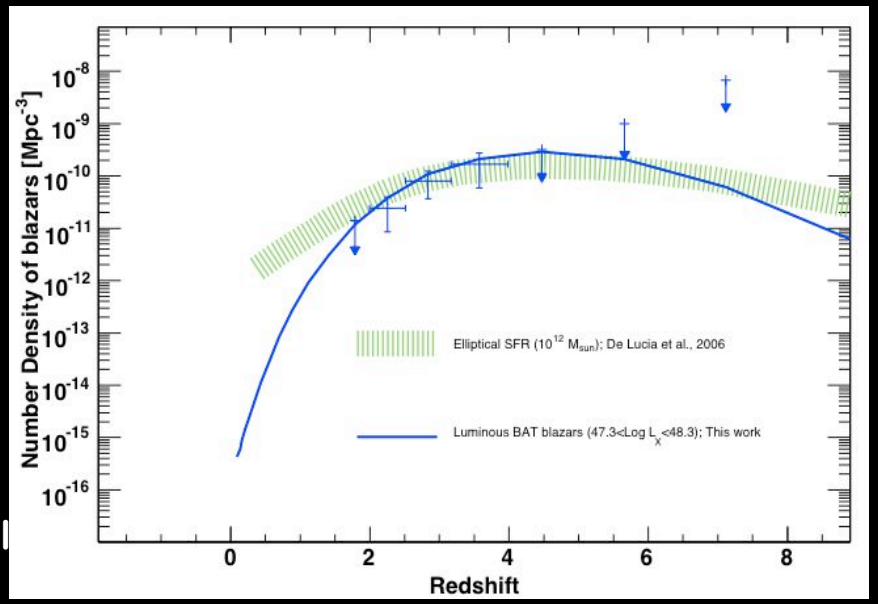
# Galaxy-AGN co-evolution

- SMBHs and galaxies co-evolve through the history of the Universe
- $M_{BH}$-$\sigma$relation (e.g.Merrit&Ferrarese01)
- Co-evolution of SFR and AGN (e.g. Madau99, Hasinger+05)




Ajell



# Conclusions

- Fermi-LAT is providing incredibly good data
- AGN (blazars) are the main populations
- Variability: no harder when brighter effect
- FSRQ show complex evolution
- Blazars might account for 30-100% of the EDB depending on their evolution (or logN-logS)
- Data are public…go and play yourself…..

# http://fermi.gsfc.nasa.gov/ssc/data/access/

Science Support Center

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+ FSSC Home

**Data**

- Data Policy
- Data Access
- Data Analysis
- Newsletter

**LAT Photon, Extended, and Spacecraft Data Query**

The Photon database currently holds 172052117 photons collected between 2008-08-04T15:43:37 and 2009-09-24T11:27:43 (239557417 and 275484463 seconds Mission Elapsed Time (MET)).

**NOTE:** For queries encompassing the whole sky (or close to it), please use the pre-generated Weekly Allsky Files.

Start Search  Reset

**NOTE:** additional selections must be applied to data downloaded from the data server prior to use in a data analysis. See **recommended data selections** and **LAT caveats** for more details.

**1. Do you want to search around a position ... ?**

**Object Name Or Coordinates:**
(e.g. '**8 34 12, -45 45 00**' or '**128.55, -45.75**' or '**Vela**')

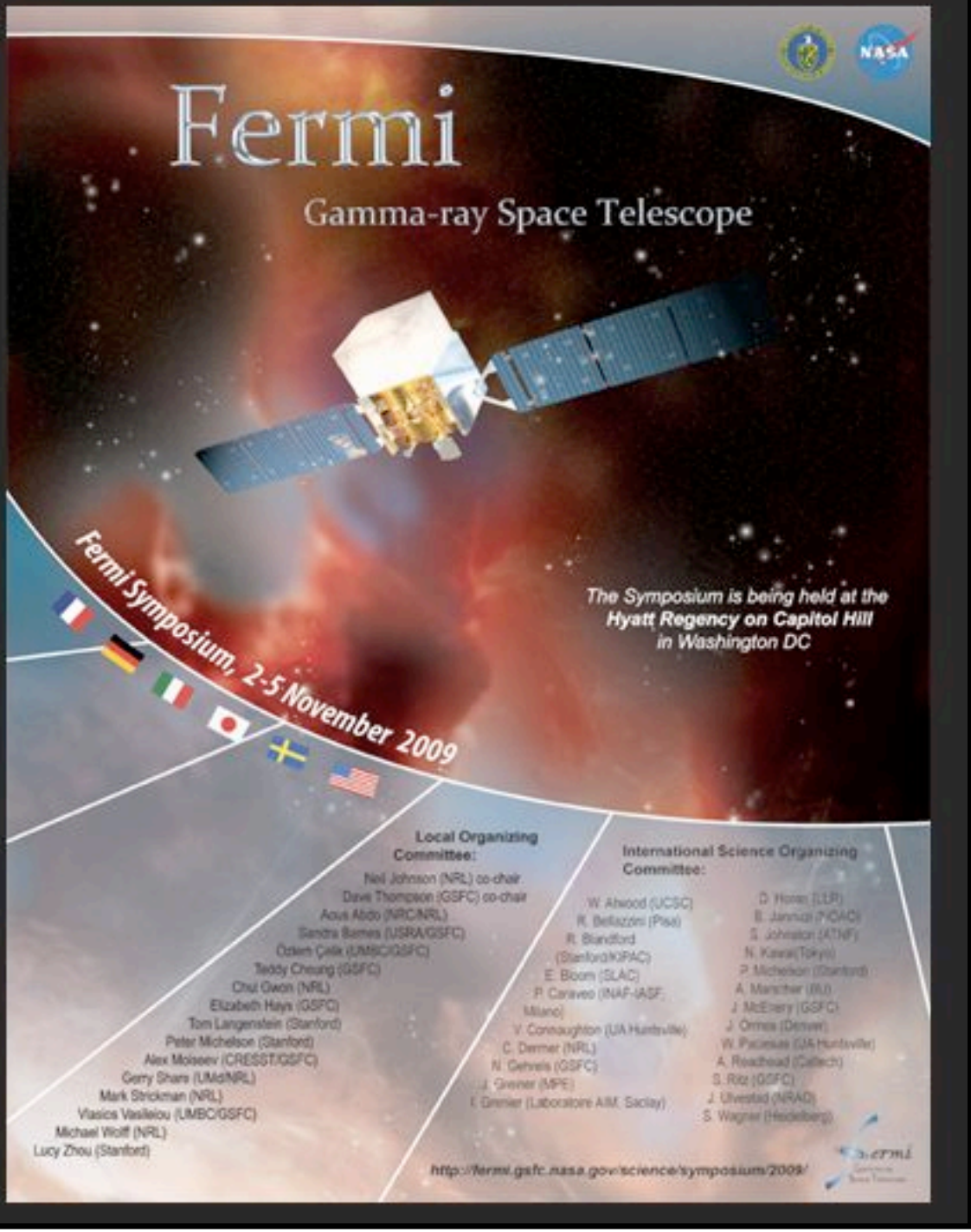
**Coordinate System:** J2000

**Selection Radius:** 15 degrees

**... and/or search by date?**

**Observations Dates:** Gregorian

**If you do not enter anything, it will return results from the past 6 months.**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Gamma-ray Space Telescope
Fermi Symposium, 2-5 November 2009
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Hyatt Regency on Capitol Hill
in Washington DC
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