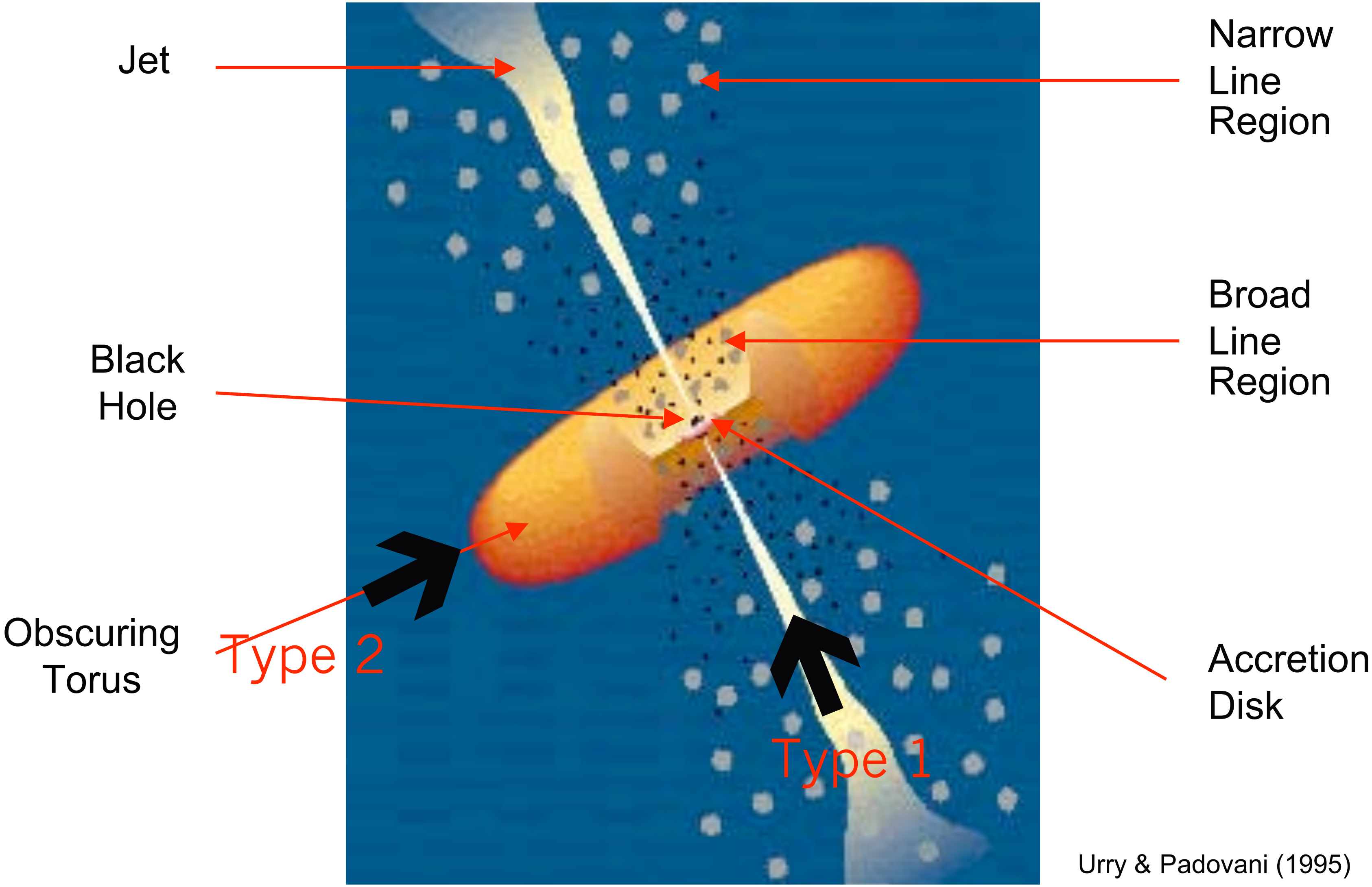
γ-ray emitting AGN and GLAST

Paolo Padovani

European Southern Observatory, Garching, Germany

- The Active Galactic Nuclei (AGN) zoo
- GeV & TeV AGN: numbers and properties
- GLAST AGN: the obvious, the likely, and the less probable

The AGN Zoo: Unified Schemes



Urry & Padovani (1995)

The AGN Zoo: Unified Schemes

	Type 2		Type 1	
Radio-quiet	Seyfert 2	→	Seyfert 1	
	QSO 2	→	QSO	
Radio-loud	high-L RG[1] → SSRQ[2]	→	FSRQ[3]	} blazars
	low-L RG	→	BL Lacs	} blazars

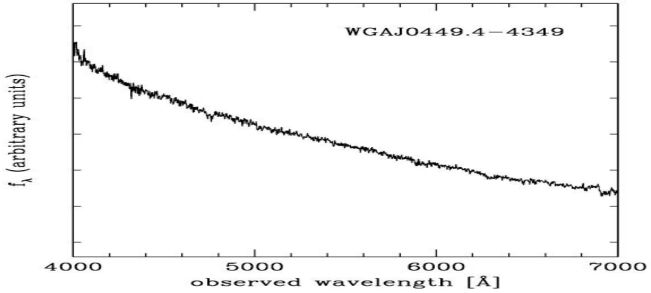
edge-on → face-on

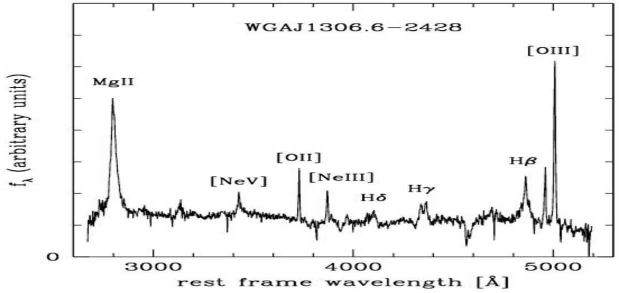
decreasing angle to the line of sight

[1] radio galaxies
[2] steep-spectrum radio quasars
[3] flat-spectrum radio quasars

Blazar Properties

BL Lacs and Flat-Spectrum Radio Quasars



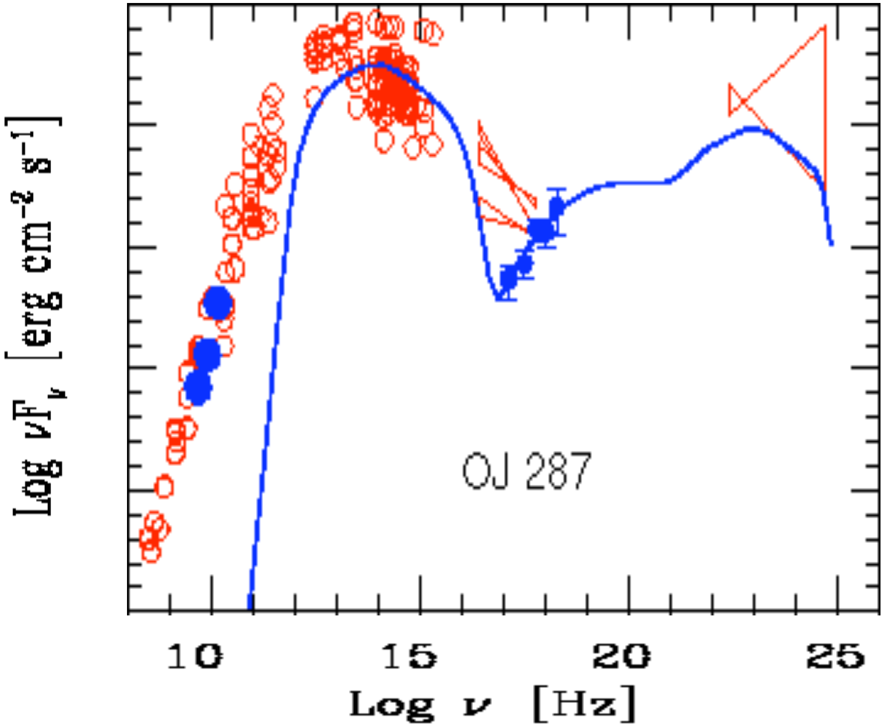


- Smooth, broad, non-thermal continuum (radio to γ-rays)
- Compact, flat-spectrum ($\alpha_r < 0.5$) radio sources ($f_{core} >> f_{extended}$)
- Rapid variability (high $\Delta L/\Delta t$), high and variable polariz. ($P_{opt} > 3\%$)
- Superluminal motion
- Indication of "beaming" ⇒ strong flux amplification = δ^p, with $\delta = 1/[\gamma(1 - [v/c]\cos\theta)]$ and $p \sim 2 - 3$ [$\delta \sim (\gamma)^{2-3} \sim 200 - 3{,}000$!]

Sites of very high energy phenomena:

$E_{max} \sim$ TeV (2×10^{26} Hz) and $\gamma_{max} \sim 40$ ($v \sim 0.9997c$)

Spectral Energy Distributions



Low-energy peaked (LBL)

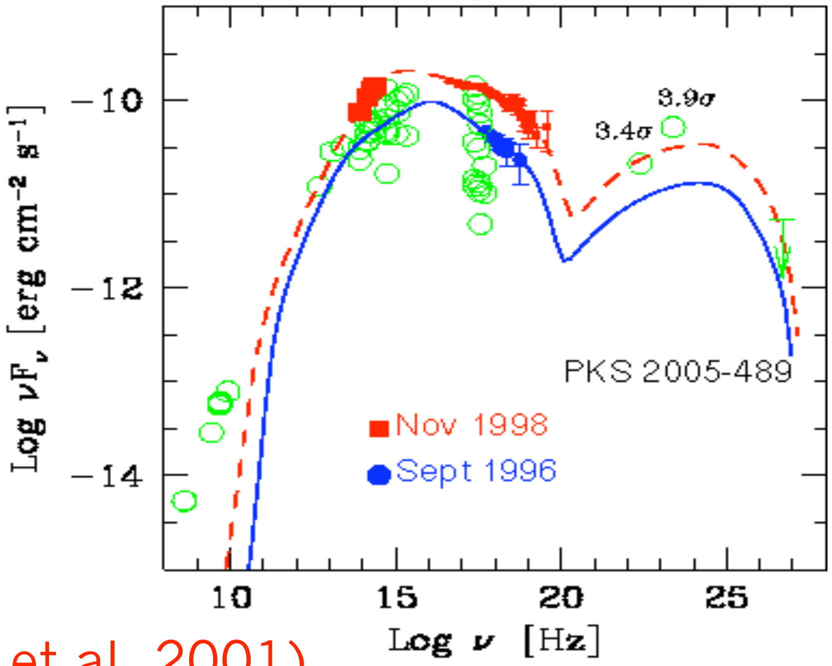
synchrotron ν_{peak} in opt/IR

X-rays: flat, IC emission

High-energy peaked (HBL)

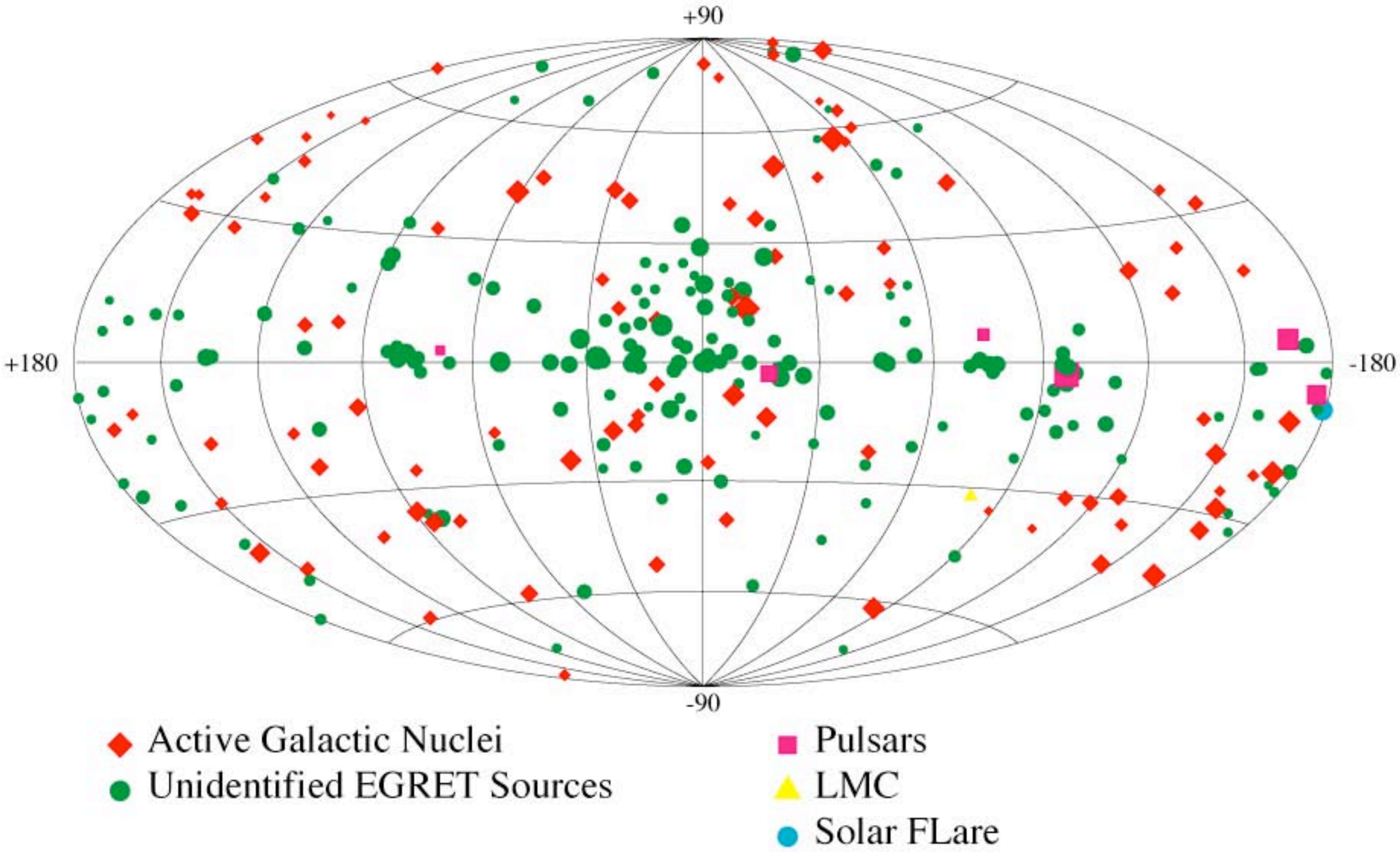
synchrotron ν_{peak} in UV/X-rays

X-rays: steep, synchrotron em.



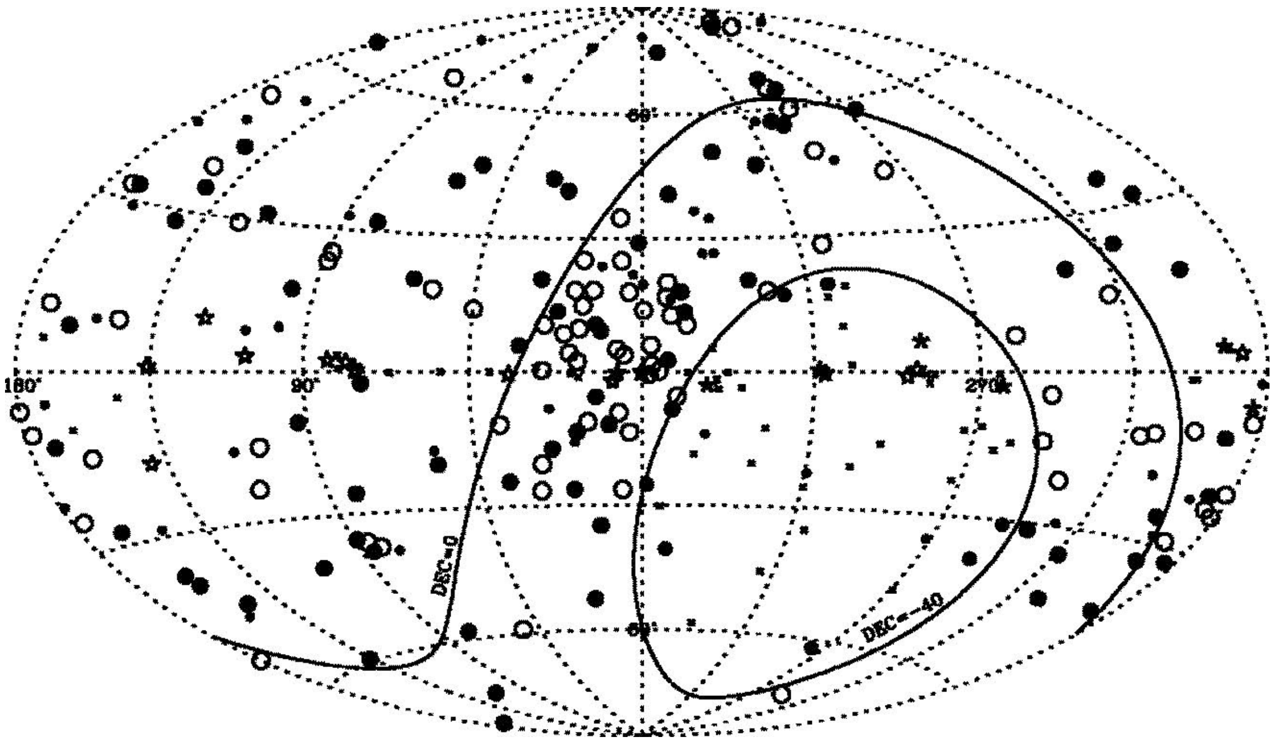
(Padovani et al. 2001)

The GeV sky



3rd EGRET catalogue (E > 100 MeV), Hartman et al. 1999, ApJS, 132, 79

The GeV sky



Large filled circle, high-confidence blazar; smaller filled circle, plausible blazar; filled star, pulsar; open star, pulsar/plerion candidate; open circle, nonblazar; cross, currently unclassified.

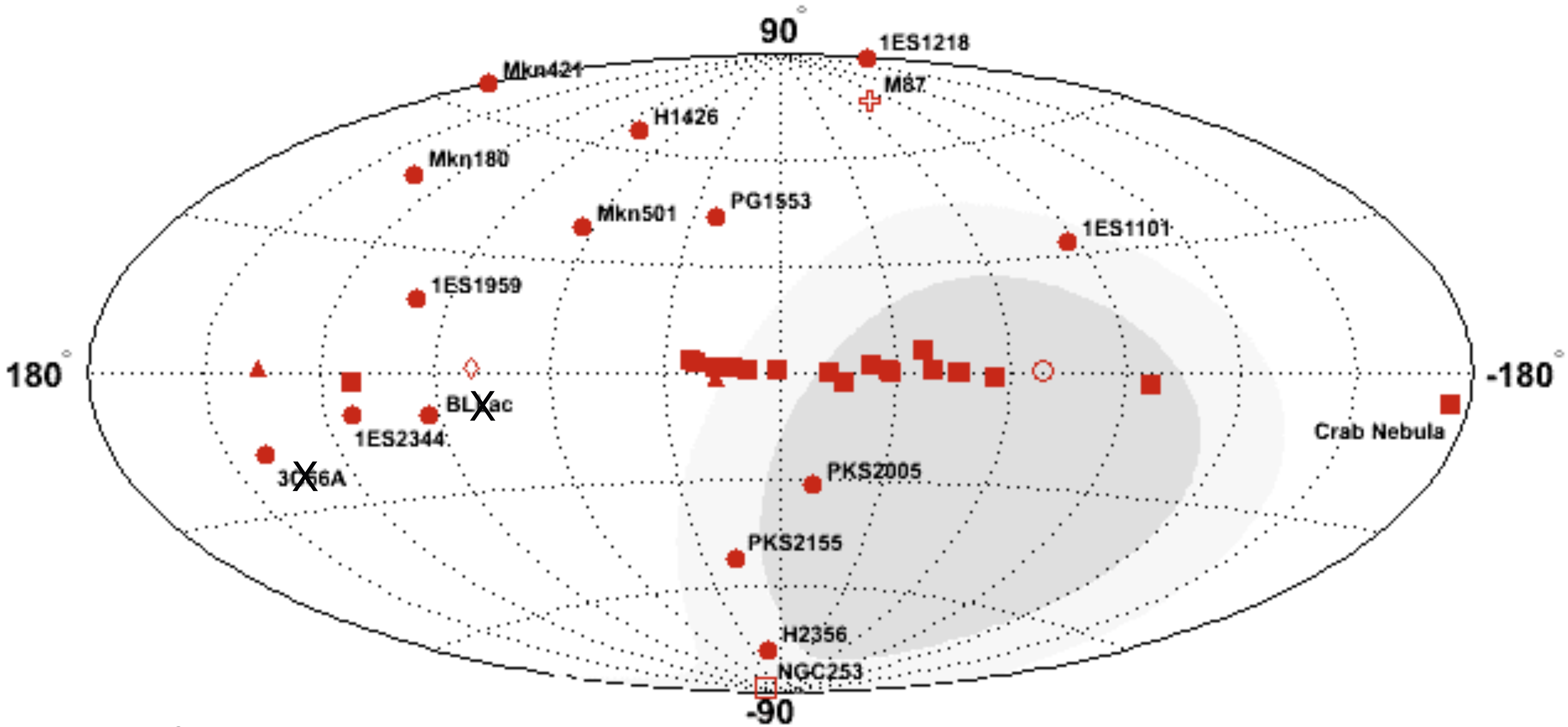
Sowards-Emmerd et al. 2004, ApJ, 609, 564; 2003, ApJ, 590, 109;
Mattox et al. 2001, ApJS, 135, 155

The GeV sky

- 271 EGRET sources
- extragalactic: ~ 130 AGN (including possible counterparts) + LMC
- AGN: all radio-loud; ~ 97% blazars + a few radio galaxies (e.g., Cen A, NGC 6251)
- Mostly FSRQ; FSRQ/BL Lac ratio ~ 3 : 1
- Mostly LBL; LBL/HBL ratio ~ 5 : 1 (HBL local: $z < 0.12$)

Most (~ 93%) EGRET detected blazars are of the "low-energy peak" type

The TeV sky



All *confirmed* extragalactic TeV sources are radio-loud AGN: 15 BL Lacs and 1 radio galaxy [M87] (a starburst galaxy is a *possible* TeV source) ⇒ ~ 94% blazars! No FSRQ, *all HBL*

from D. Mazin, Barcelona Conf., July 2006 (astro-ph/0609152)
+ L. Costamante, p.c.

Blazar Rareness

Probability of having a jet pointing at us is small; for $\theta_{max} \sim 15°$:

$\sim$ 3% of radio-loud AGN, ≈ 0.3% of all AGN,

≈ 0.003 - 0.03% of normal galaxies

Only 1 out of ≈ 3,000 - 30,000 galaxies is a blazar!

Why have then blazars been detected in the γ-ray band?
Because they have:

1. High-energy particles, which can produce GeV and TeV photons
2. Relativistic beaming, otherwise GeV (Tev) photons would be absorbed through photon-photon collision with X-ray (IR) photons
3. Strong non-thermal jet component

Which AGN will GLAST detect?

- More of the same: flat-spectrum radio quasars, BL Lacs

- How many more? Answer depends on: evolution, intrinsic number density (cf. counts in other bands), γ-ray duty cycle, SED, and background. Simple assumptions:

  ✓ ~130 EGRET-detected blazars (likely lower limit)

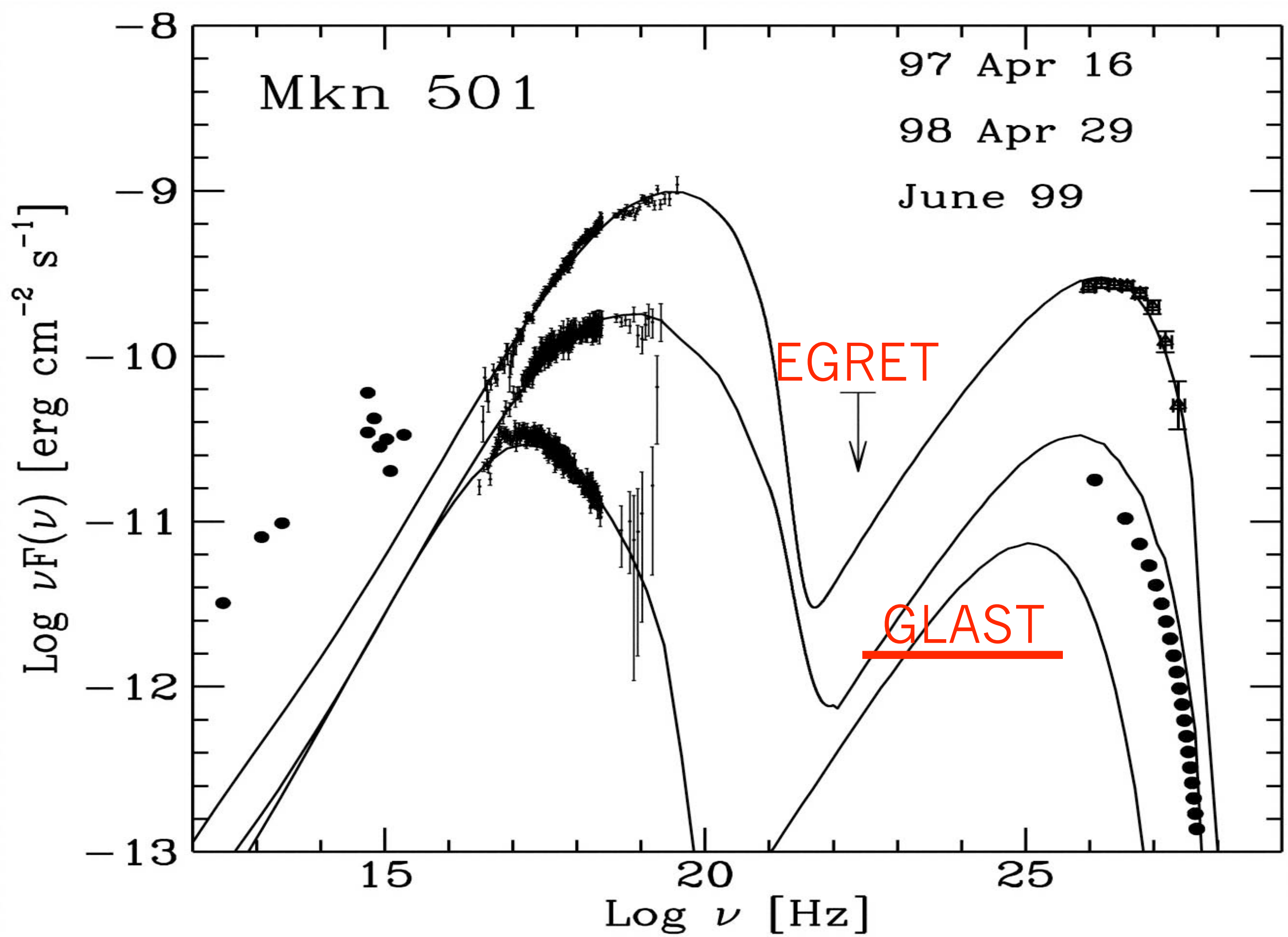
  ✓ Euclidean number counts [$N(>S) \propto S^{-1.5}$] (upper limit)

  ✓ GLAST ~ 30 x more sensitive than EGRET

  ⇒ ≤ 20,000 blazars (~0.5 deg^{-2} == surface density of DXRBS blazars down to f_{5GHz} ~50 mJy: Padovani et al., ApJ, submitted)

- Giommi & Colafrancesco (2006) predict ≈ 5,000 (Monte Carlo simulations)

MKN 501: a TeV/non-GeV BL Lac



Tavecchio et al. 2001, ApJ, 554, 725

1ES2344+514: a TeV/non-GeV BL Lac

Observation of VHE γ-rays from 1ES 2344+514 7

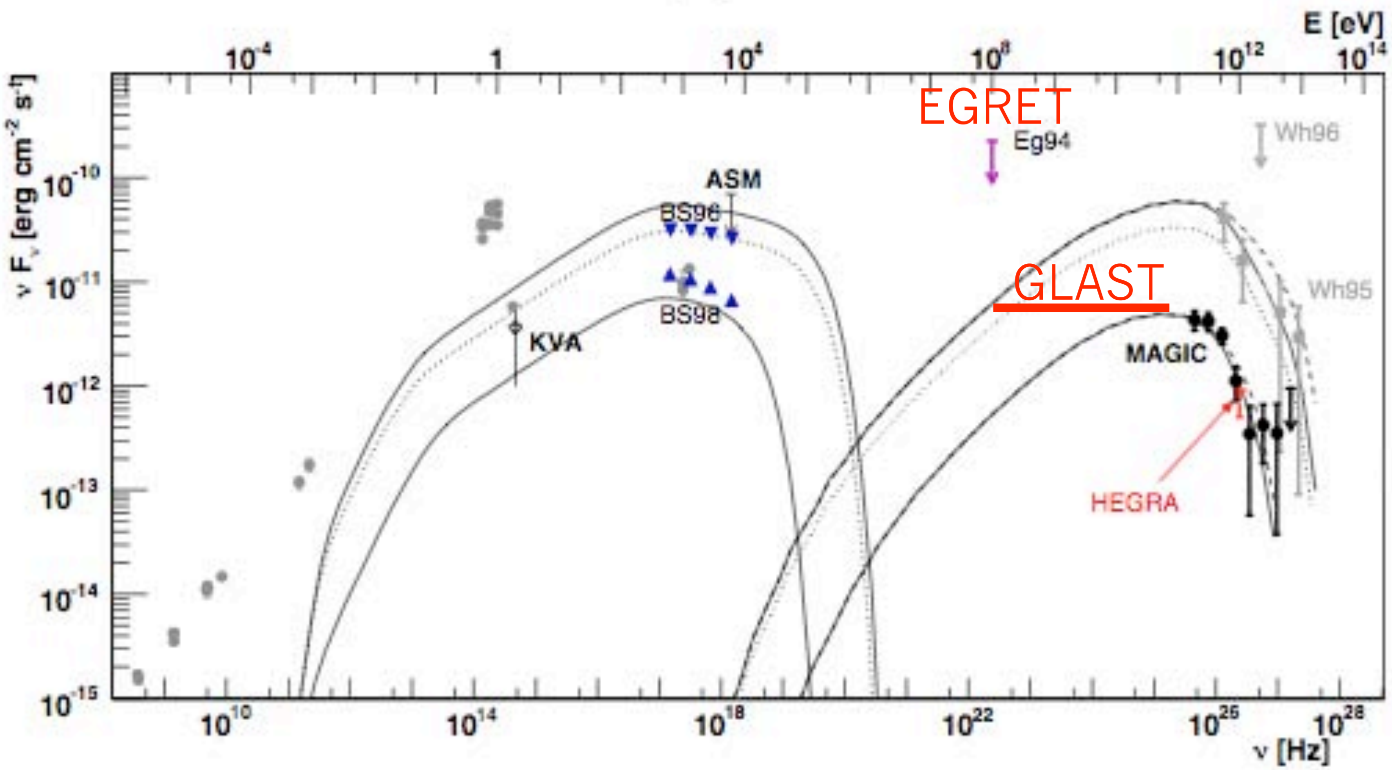
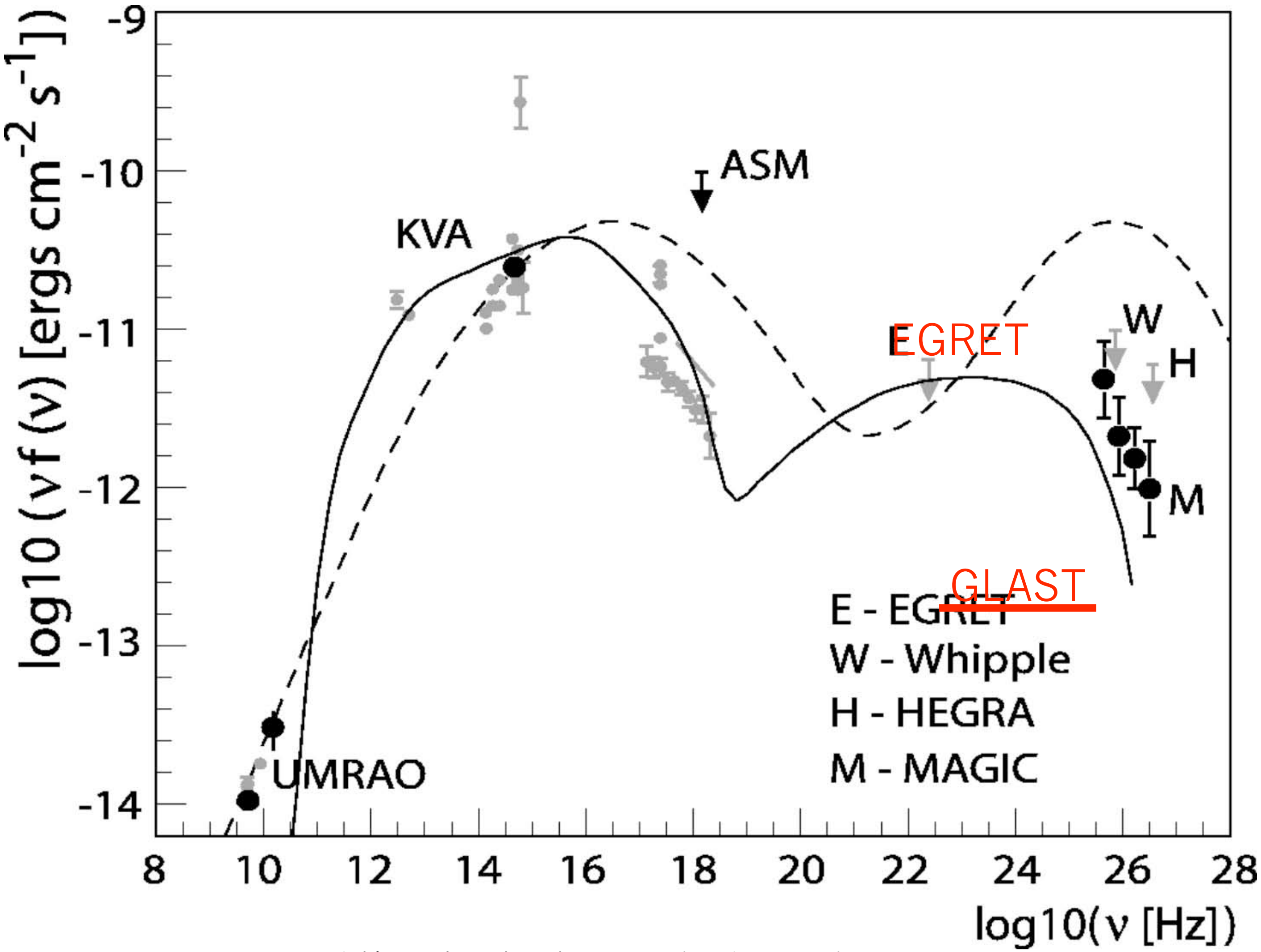


FIG. 7.— Overall SED for 1ES 2344+514. Gray symbols: Archival (radio, optical, X-ray) data taken from Giommi et al. (2002); Schroedter et al. (2005). The two *BeppoSAX* data sets represent a quiescent state and data taken simultaneously with Whipple observations: BS96—*BeppoSAX* 1996 December 05; BS98—*BeppoSAX* 1998 June 28. Wh95—Whipple flare spectrum; Wh96—Whipple upper limit corresponding to the BS96 measurement (Schroedter et al. 2005). Eg94—*EGRET* upper limit (Hartman et al. 1999). HEGRA 1998-2002 flux point (Aharonian et al. 2004a); MAGIC—this paper; data taken simultaneously with the MAGIC measurements: KVA: Optical flux, host galaxy contribution subtracted; ASM: RXTE-ASM upper limit. The solid curves were obtained using the model given in Krawczynski et al. (2004) and describe the synchrotron and IC emission. The corresponding intrinsic (EBL de-absorbed) spectra are indicated by the dashed curves. The solid lines model the flare state of 1995 and the low state as seen by MAGIC in 2005. The dotted curve is to describe the BS96/Wh96 observation and only differs in a lower Doppler factor ($\delta = 13.2$) from the Whipple flare model.

Albert et al. 2006, ApJ, submitted (astro-ph/0612383)

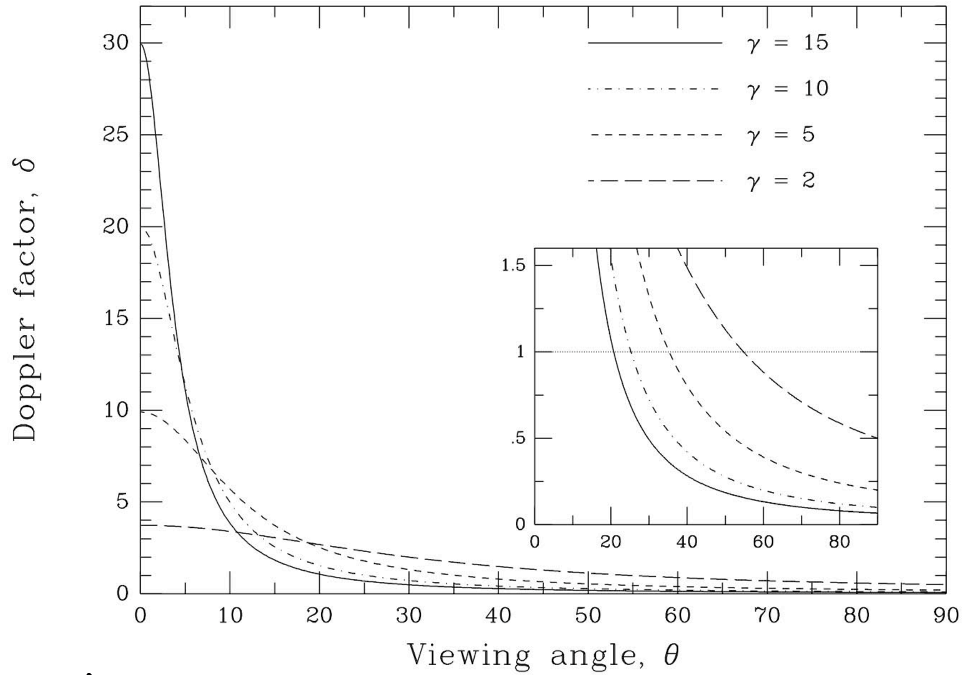
MKN 180: a TeV/non-GeV BL Lac



Albert et al. 2006, ApJ, 648, L105

Radio-galaxies as γ-ray sources?

- Many more radio-galaxies than blazars (≈ 30 times)
- For angles > 20 - 30° jet emission ($\propto \delta^{2-3}$) is de-amplified ⇒ radio-galaxies should be weaker (γ-ray) sources than blazars by factors > 100 - 1,000



- Indeed, the (∼ 3) GeV and TeV detected radio-galaxies are very close (z < 0.02)
- But …

Radio-galaxies as γ-ray sources?

- Large scale (> kpc, as opposed to the pc scale) jet emission?
  - ✓ unlikely to be relevant for most radio-galaxies (Stawarz, Sikora, & Ostrowski, 2003, ApJ, 597, 186)
- Structured/decelerated jets? Fast spine/slow layer (Ghisellini, Tavecchio, & Chiaberge, 2005, A&A, 432, 401) or decreasing bulk Lorentz factor (Georganopoulos, Perlman, & Kazanas, 2005, ApJ, 634, L33). [Structured jet suggested by VLBI observations (*limb brightening*)]
  - ✓ Main idea: each component sees enhanced radiation field coming from other component ⇒ inverse Compton (high-energy) radiation gets boosted
  - ✓ GeV emission is higher as compared to predictions based on homogeneous jets (but many free parameters)
  - ✓ Assuming γ-ray/radio flux ratio observed for 3 sources is typical, Ghisellini et al. (2005) predict ≥ 10 3CR radio-galaxies to be detected by GLAST

Radio-quiet AGN as γ-ray sources??

- Most AGN have very weak radio emission, on average ~1,000 times smaller than in the so-called radio-loud sources
- What is the nature of radio emission in these sources?
  Two extreme options:
  1. related to star-formation processes
  2. scaled down version of that present in radio-loud AGN
- If n. 2, then radio-quiet AGN are also expected to be γ-ray sources, but at very low flux levels, on average ~30 below the GLAST limit. Perhaps detection is possible for high radio flux/radio-quiet AGN?? Need <u>core</u> radio flux, say, > 100 mJy
- Even negative detection (supported by detailed calculations) could prove very valuable!

Summary

1. Blazars, although very rare sources, dominate the γ - ray sky
2. GLAST will *certainly* detect "many thousand" blazars
3. GLAST will *most likely* detect many "high-energy peaked" blazars (unlike EGRET)
4. GLAST will *possibly* detect a "fair" number of radio-galaxies
5. Could GLAST detect also radio-quiet AGN???
6. GLAST will constrain (radio-loud) AGN physics and populations (see next talks and posters!!)