Misaligned AGN with Fermi-Lat: a different perspective on relativistic jets

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on behalf of the
FERMI LAT Collaboration

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BACKGROUND

Within the AGN Unified Model, an increase of the angle of view implies a de-amplification of the jet emission that can be quite severe even at relatively small angles.

As a consequence, large inclination Radio Sources should be lost by γ-ray satellites if a pure, one-zone homogeneous, synchrotron self-Compton model is adopted.

The first EGRET gamma-ray (and later onTeV) detections of Radio Galaxies (i.e. CenA, NGC 6251, M87) questioned this simple approach suggesting a more complex jet structure.

- Decelerating jet (Georganopoulos & Kazanas 2003)
- Structured (spine +slower layers) jet (Stawarz & Ostrowski 2003, Ghisellini, Tavecchio & Chiaberge 2005)

The LAT-Fermi detection of new misaligned sources is opening a new field of research, that we can explore...

WHAT WE INTEND FOR MISALIGNED AGNs: A PRAGMATIC APPROACH

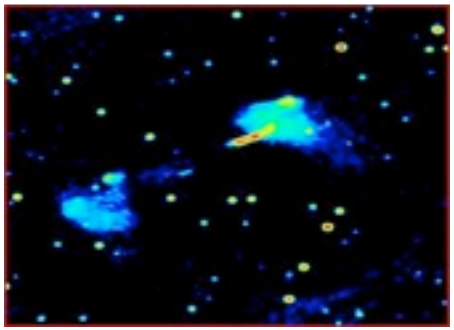
Misaligned sources (RG, SSRQ) are AGNs showing

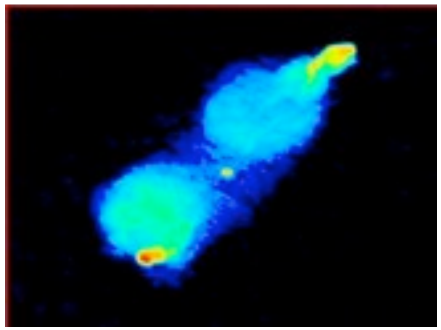
- resolved and possibly symmetrical structures in radio maps
- steep radio spectra (α_r>0.5) .

FR I The separation between the points of peak intensity in the two lobes is smaller than half the largest size of the source. (R<0.5) . $P_{178\ MHz}$ <10^{25} Watt Hz^{-1} sr^{-1}

FR II: The separation between the points of peak intensity in the two lobes is greater than half the largest size of the source (R>0.5). $P_{178\ MHz}$ >10^{25} Watt Hz^{-1} sr^{-1}

NGC6251 – FRI





3C 390.3 - FRII

FRI are considered the PARENT POPULATION of BL LACs

FRII are considered the PARENT POPULATION of FSRQs (SSRQs are in between)

SEARCH FOR Steep Spectrum Radio Sources:

The 3CR, 3CRR and MS4 samples are cross-correlated with the 15 month-LAT-list of AGN candidates

3CRR sample (Laing et al. 1983)

Frequency: 178 MHz.
Flux density: F(178 MHz) > 10.9 Jy
Declination range: > = 10 deg
Galactic latitude threshold |b|>10 deg
No. of sources: 173

3CR sample (Bennett, 1962; Spinrad et al. 1965)

Frequency: 178 MHz.
Flux density: F(178 MHz) > 9 Jy
Declination range: Dec > -5 deg
Galactic latitude threshold |b|>10 deg
No. of sources: 298

Molonglo Southern 4Jy Sample (Burgess & Hunstead 2006)
from the Molonglo Reference Catalogue (MRC):

Frequency: 408 MHz.
Flux density: F(408 MHz) > 4 Jy
Declination range: [-85,-30] deg
Galactic latitude threshold |b| > 10 deg
No. of sources: 228

- The low-frequency selection criteria (178 and 408 MHz) select radio sources primarily on the relatively steep spectrum synchrotron emission of their extended lobes
- Radio (FRI vs FRII) and optical (Radio Galaxy vs Quasar) classifications are available for the majority of the sources.
- These surveys cover most part of the northern and southern sky

Cross Correlation Results:

7 FRI -- 4 FRII

Table 1: The Sample

Object	1FGL Name	RA (2000)	Dec (2000)	Redshift	Class Radio	Class Optical	Log (CD) at 5 GHz	ref	Cat.
3C 78/NGC 1218	1FGLJ0308.3+0403	03 08 26.2	+04 06 39	0.029	FRI	G	-0.45	1	3CR
3C 84/NGC 1275	1FGLJ0319.7+4130	03 19 48.1	+41 30 42	0.018	FRI	G	-0.19	2[a]	3CR
3C 111	1FGLJ0419.0+3811	04 18 21.3	+38 01 36	0.049	FRII	BLRG	-0.3	3	3CRR
3C 120		04 33 11.1	+05 21 16	0.033	FRI	BLRG	-0.15	1	3CR
PKS 0625-354	1FGLJ0627.3-3530	06 27 06.7	- 35 29 15	0.055	FRI	G	-0.42	1	MS4
3C 207	1FGLJ0840.8+1310	08 40 47.6	+13 12 24	0.681	FRII	SSRQ	-0.35	2	3CRR
PKS 0943-76	1FGLJ0940.2-7605	09 43 23.9	- 76 20 11	0.27	FRII	G	< -0.56	4	MS4
M87/3C 274	1FGLJ1230.8+1223	12 30 49.4	+12 23 28	0.004	FRI	G	-1.32	2	3CRR
CENA	1FGLJ1325.6-4300	13 25 27.6	- 43 01 09	0.0009[b]	FRI	G	-0.95	1	MS4
NGC 6251	1FGLJ1635.4+8228	16 32 32 .0	+82 32 16	0.024	FRI	G	-0.47	2	3CRR
3C 380	1FGLJ1829.8+4845	18 29 31.8	+48 44 46	0.692	FRII/CSS	SSRQ	-0.02	2	3CRR

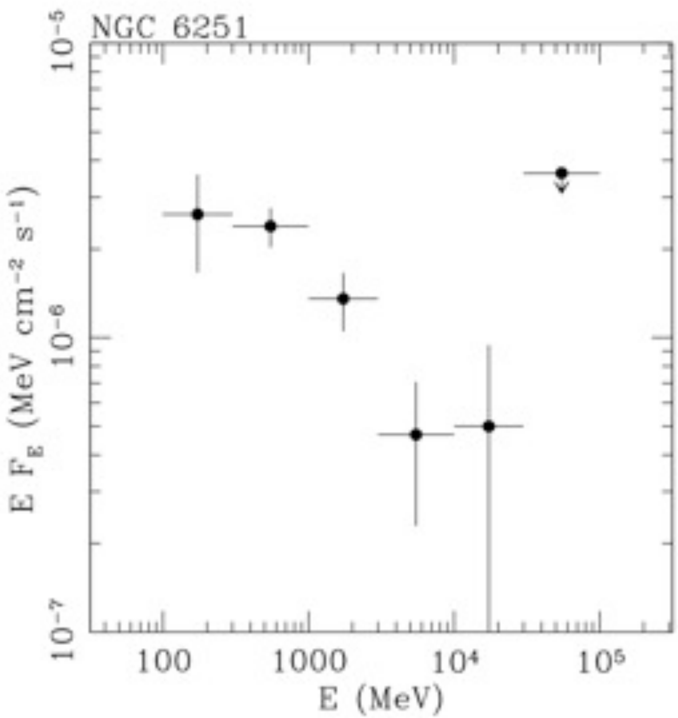
NGC 1275, M87 and CENA have been already studied in dedicated papers

Analysis of the sample using 15-month-data: 4 Aug 2008- 4 Nov 2009

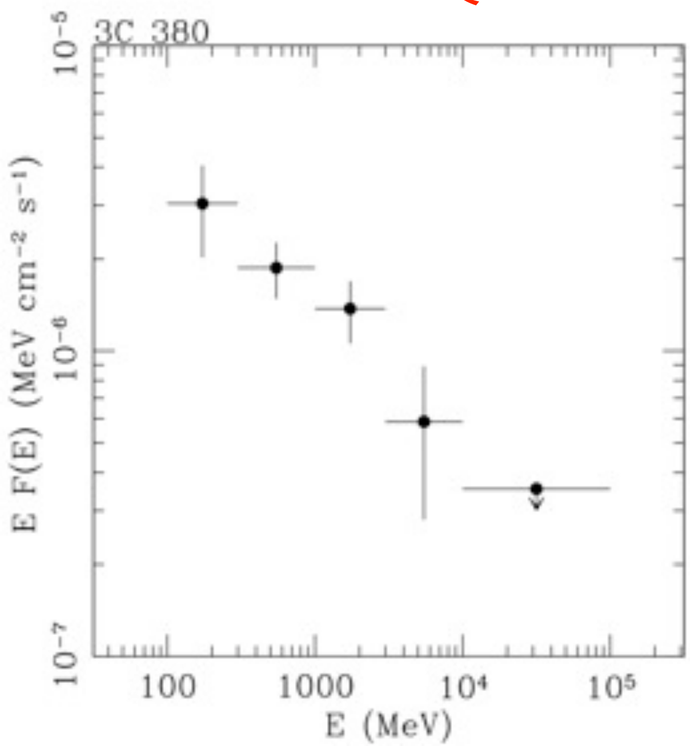
MAGN

- are generally faint sources: F(>100 MeV) ~ 10^{-8} Phot cm^{-1} s^{-1}
- and soft (Γ ~ 2.4) with photon energies mostly between 0.1-10 GeV
- do not show time variability on time scale of months (low statistics).

FR I Radio Galaxy



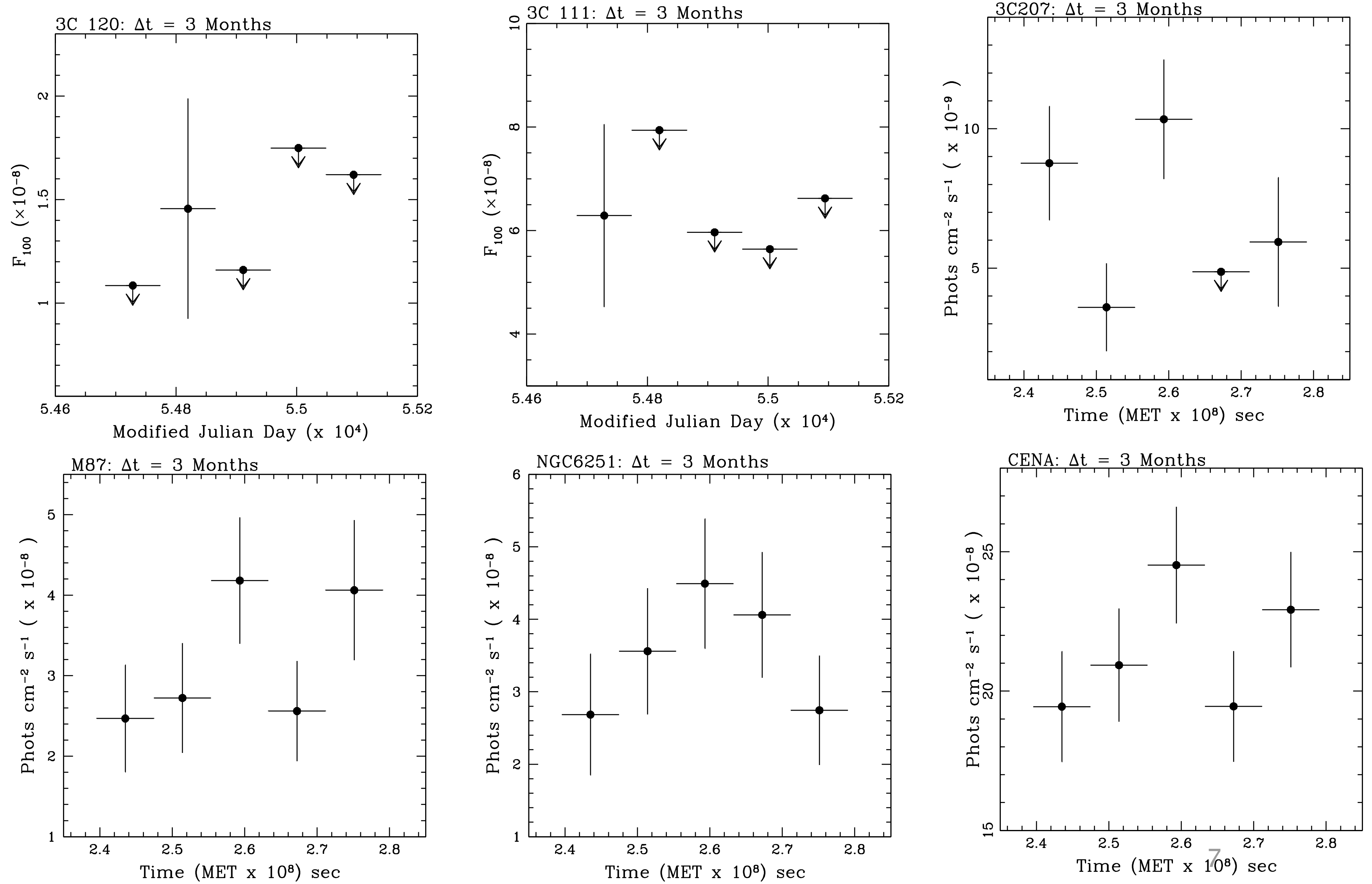
FRII SSRQ



Spectral and time variability (15-month-data)

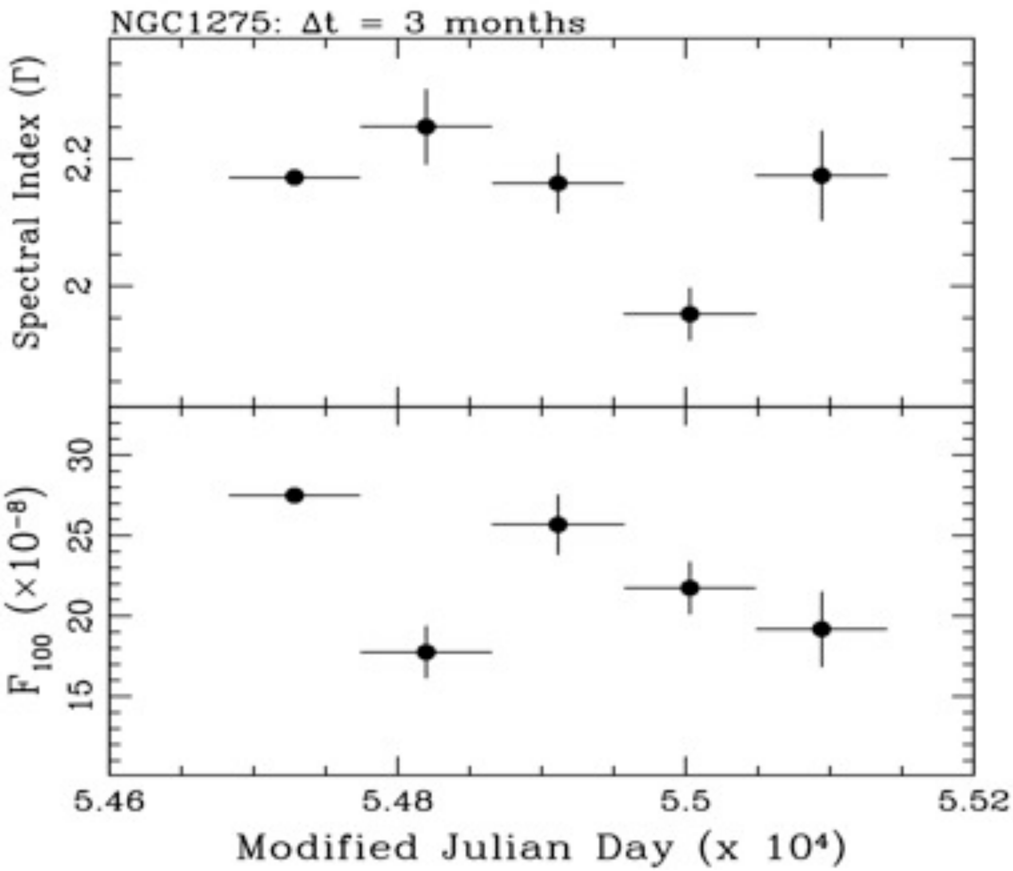
MAGN

- do not show time variability on time scale of months (low statistics).



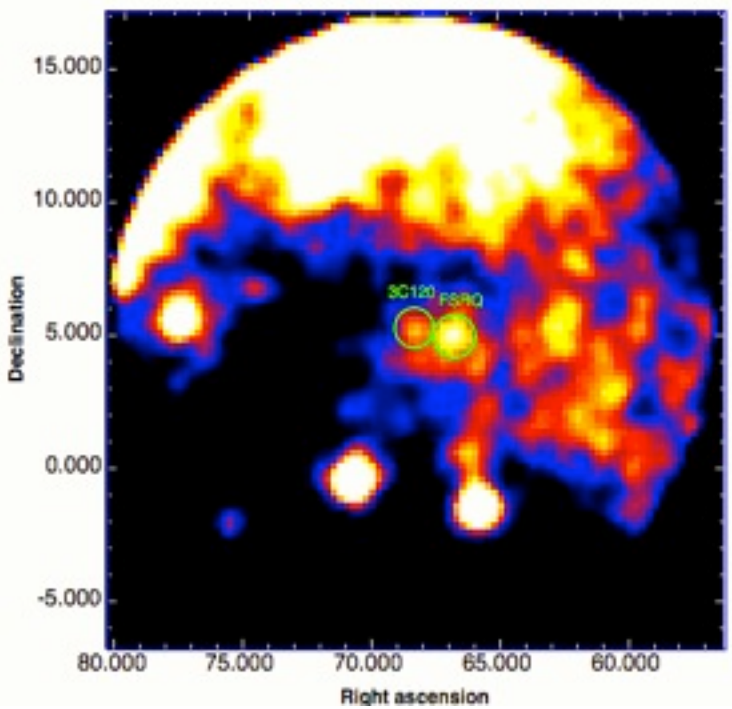
Low statistics generally prevent the detection of time variability

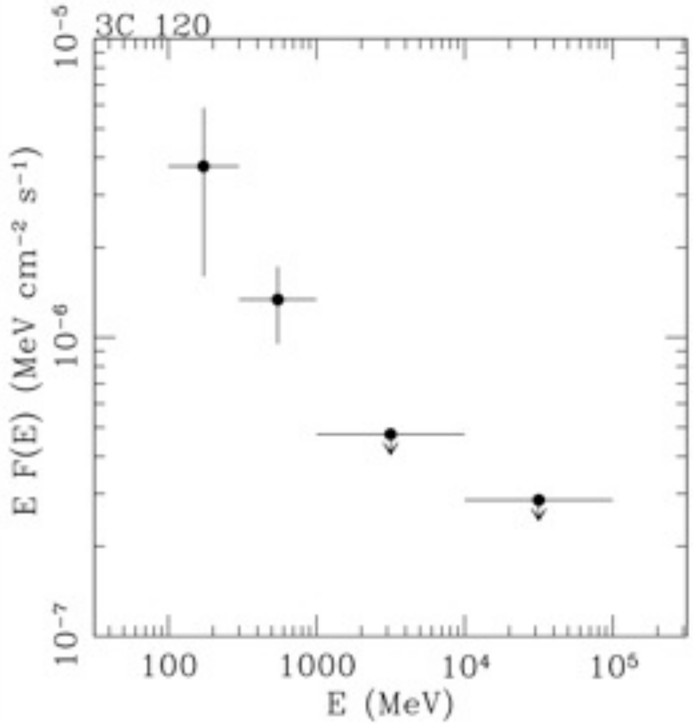
NGC 1275 is the only source showing variability (Kataoka et al. 2010)

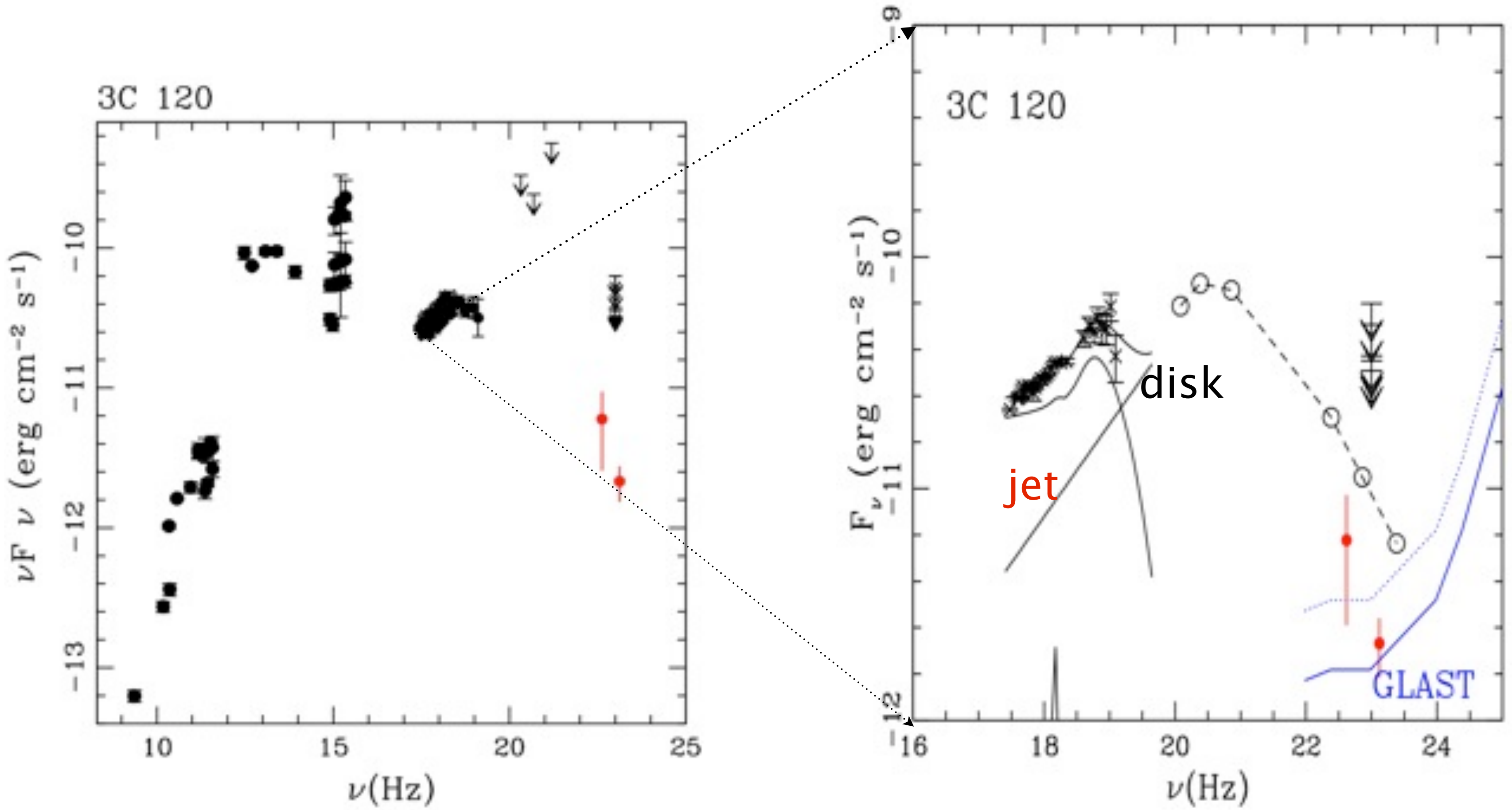


Detection of the Broad Line Radio Galaxy 3C 120 (FRI)

Source	TS	Γ	Flux (10^{-8} Phot/sec/cm^2) 0.1-100 GeV	Log Lum (erg/sec) 0.1-10 GeV
3C120	32	2.71±0.35	2.9± 1.7	43.43







Grandi & Palumbo (2007) suggested Broad Line Radio Galaxies as possible GLAST candidates assuming a combination of thermal (accretion flow) and non-thermal emission (jet) in the 2-10 keV band.

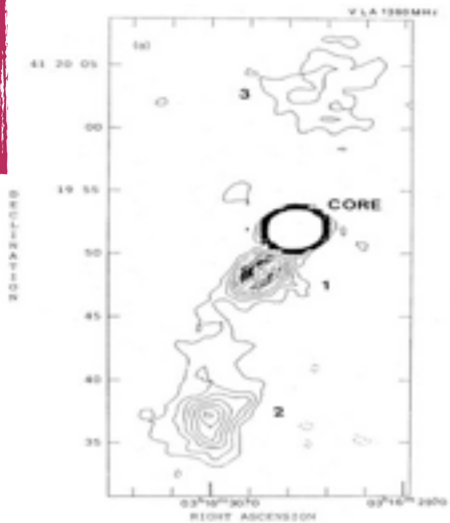
The FERMI detection of 3C120 (3C111) can help in separating the jet and disk contribution in Radio Loud AGNs.

Where do the γ–rays photons come from?

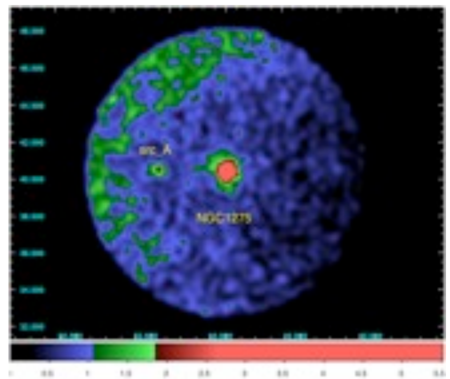
➡ from small regions (10^{16}–10^{18} cm) near the radio core

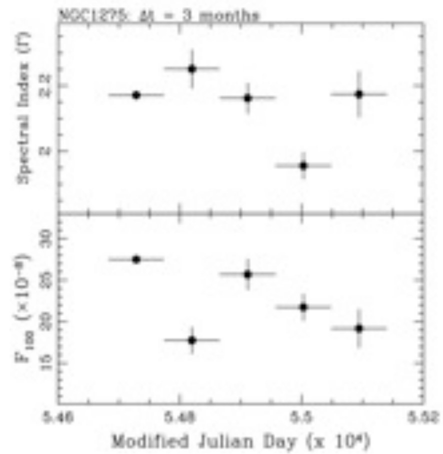
NGC1275

Abdo et al. 2009, Kataoka et al. 2010



LAT IMAGE

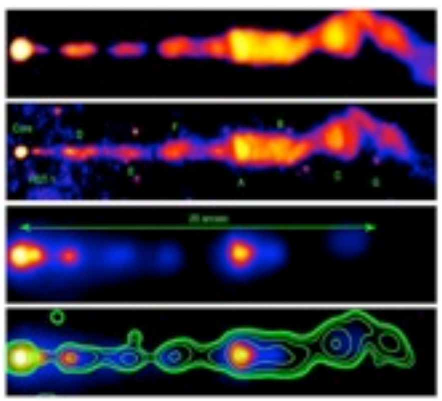




Time variability on time scale of months

M87

Abdo, A. et al.2009



TeV (>350 GeV): flux variation Δt~1 day (Aharonian et al. 2006, Albert et al. 2008, Acciari et al. 2008,2009)
VLBI core increases during the flare
High energy photons are produced at 30-60 R_S

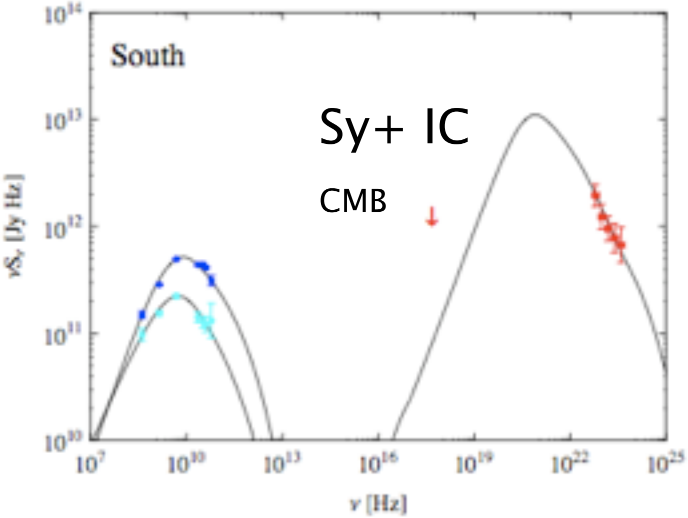
but also

➡ from large extended regions (kpc–scale structures)

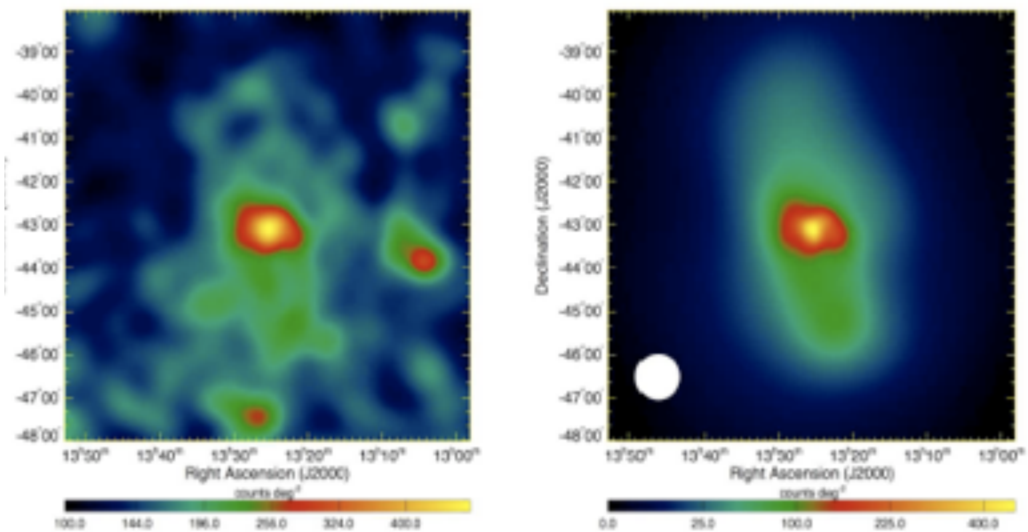
CenA Lobes

Abdo et al. 2010 Science

Inverse Compton of CMB by relativistic electrons



Fermi-LAT (>200 MeV) counts maps



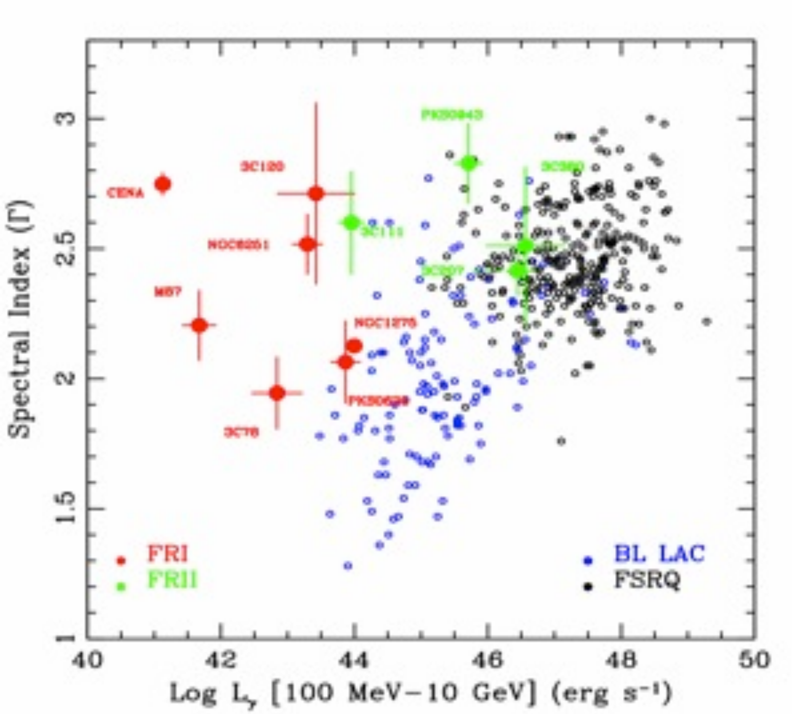
n (ε): broken pl + exp cutoff

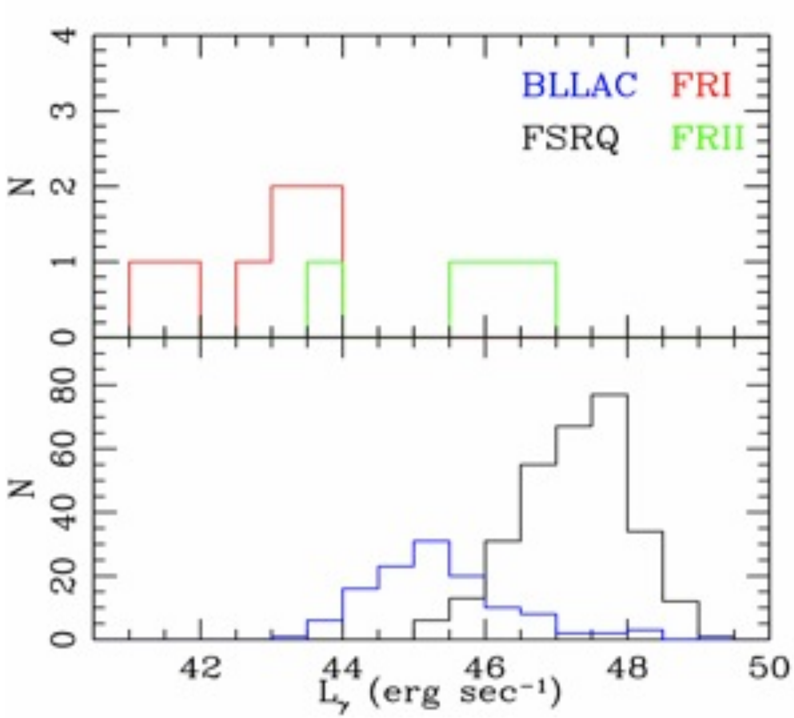
B ~ 0.9 μG U_e/U_B~2–4

Detection significances: N Lobe 5σ- S Lobe 8σ

Which physical processes occur at pc-scales?

MAGNs versus Blazars



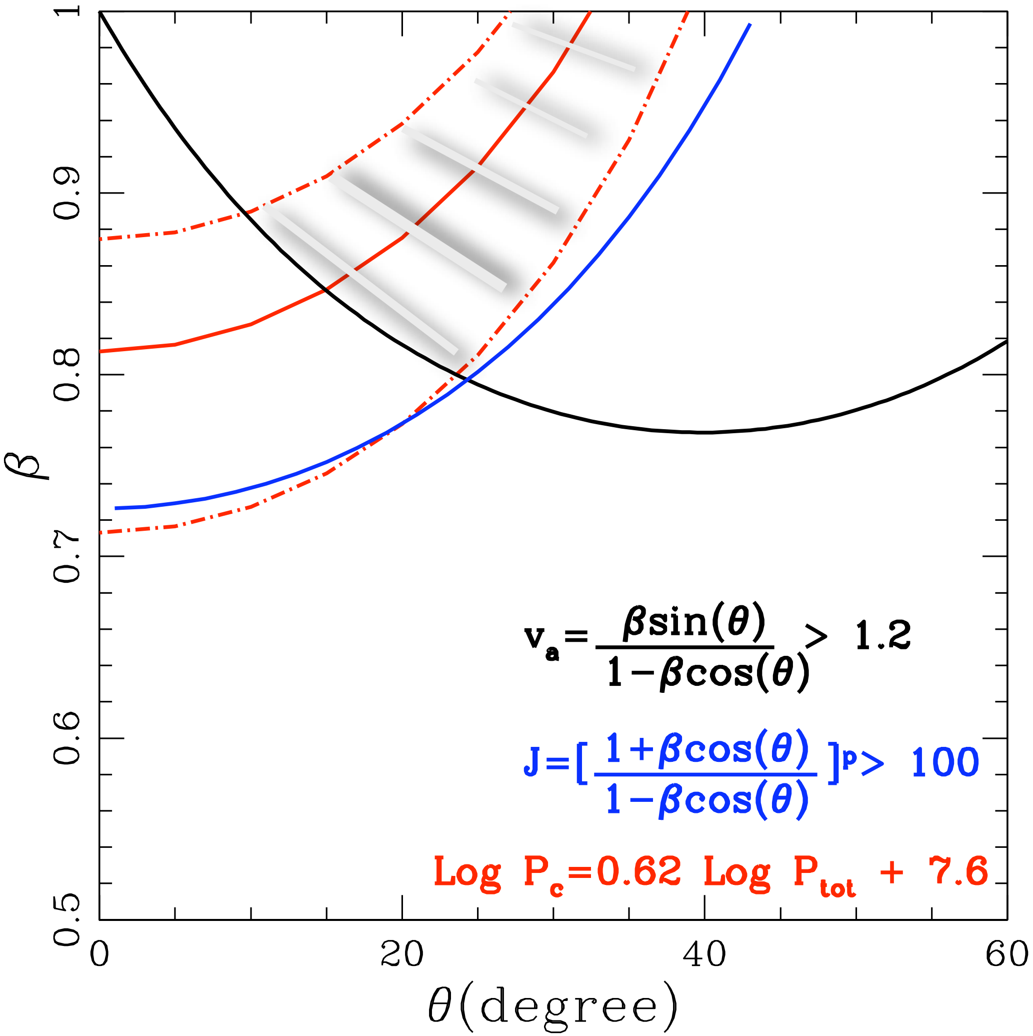


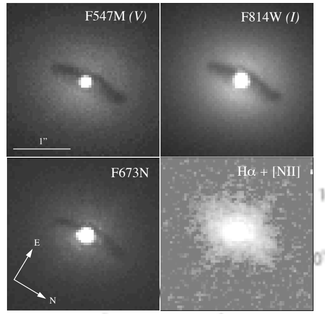
Misaligned AGNs generally occupy a separate region in the Lγ-Γ plane.

In agreement with the idea that misaligned AGNs have smaller beaming factor $\delta = 1/\Gamma(1-\beta\cos\theta)$

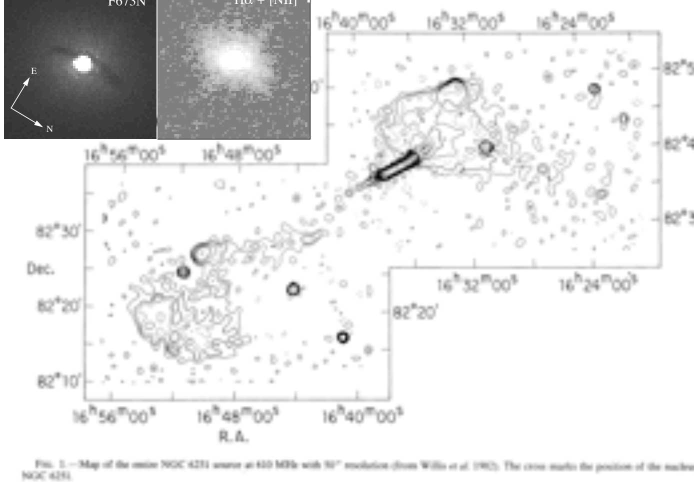
The case of NGC 6251

FRI Radio Galaxy z=0.024





Ferrarese & Ford 1999



Observational constrains:

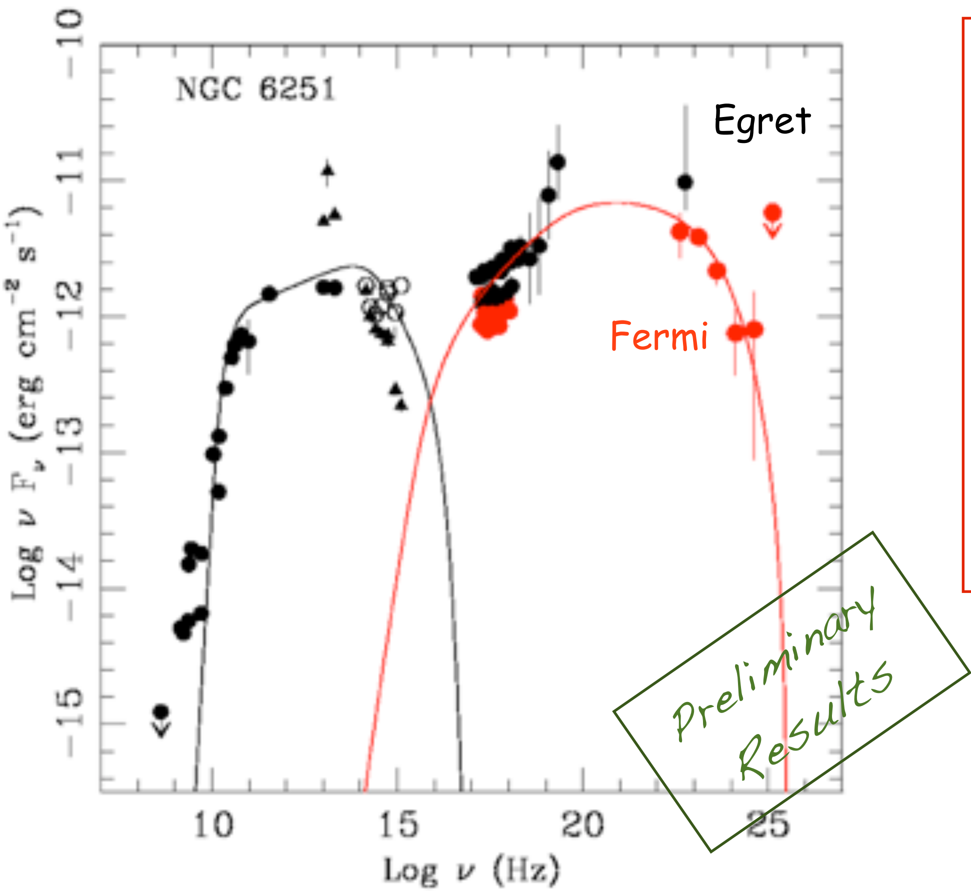
Radio ➟ (ϑ , R)

(Jones &Wehrle, 1999; Giovannini et al. 2001; Waggett 1997)

ϒ-ray variability ➟ (R)

Egret observed NGC625 in a higher state (Mukherjee et al. 2002)

Nuclear SED Modelling: SSC



SSC Model for NGC6251 already proposed by Guainazzi et al. 2003, Chiaberge et al. 2003

Model Parameters:

$\vartheta = 25^{\circ}$ $R=10^{17}$ cm $\Gamma=2.4$!!!

$B=0.04$ G

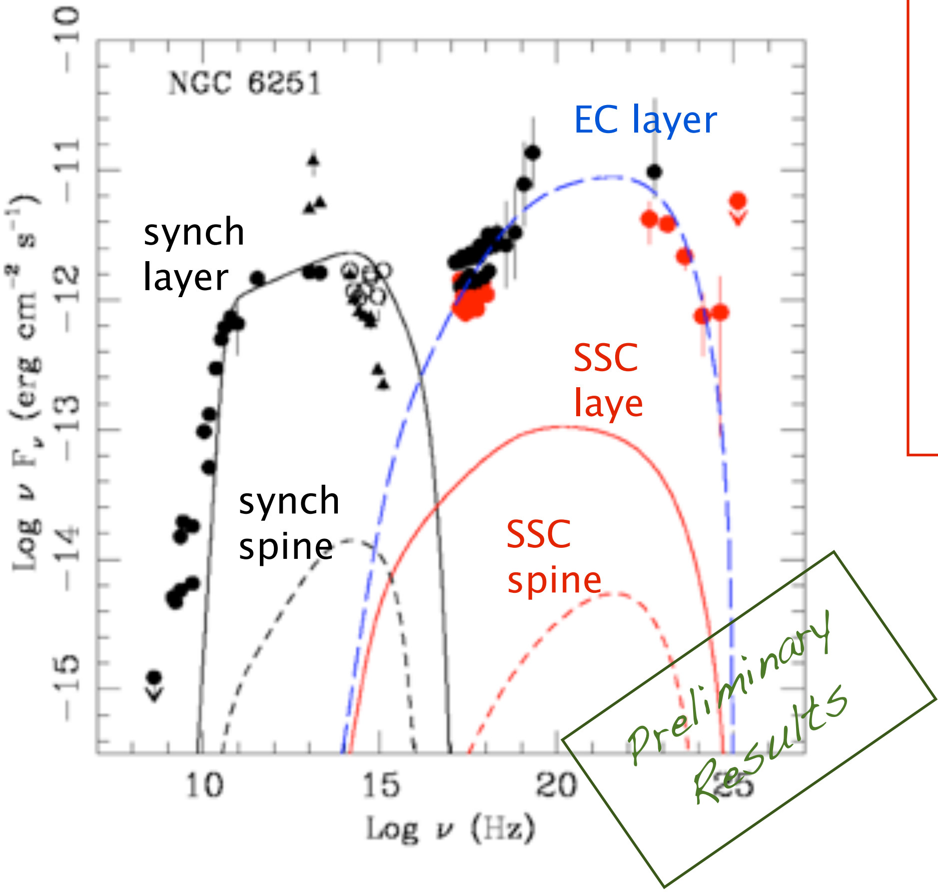
$N(\varepsilon)=\varepsilon^{-p}$ $p_1=2.76$ $p_2= 4.04$

$\varepsilon_{break} = 2\times10^4$

$\varepsilon_{min} = 250$ $\varepsilon_{max} = 2\times10^5$

The Jet is slow compared with typical BL Lac objects

Nuclear SED Modelling: spine-layer jet

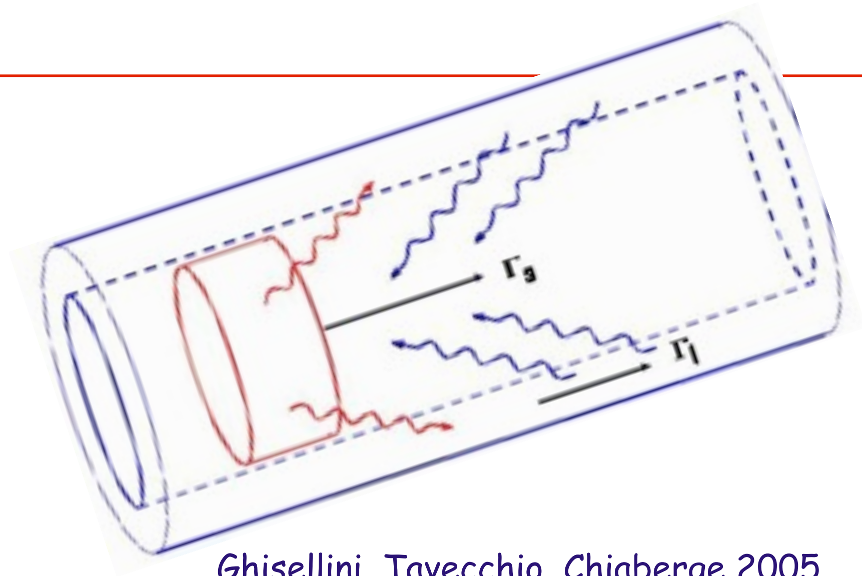


Model Parameters:

$\vartheta = 25^\circ$

Layer: Γ=2.4 B=0.7 G
R =10^{17} cm h=3*10^{16} cm

Spine: Γ=15 B=1.8 G
R=10^{16} cm h=10^{15} cm



Ghisellini, Tavecchio, Chiaberge 2005

Jet Kinetic Powers

- <u>SSC model:</u>
- $L_p \sim 5*10^{44}$ erg s^{-1}
- $L_B \sim 4*10^{41}$ erg s^{-1}
- $L_r \sim 2*10^{43}$ erg s^{-1}

Slow and Heavy Jet

- Unified Scheme and BL Lac?

- Acceleration & Confinement ?

(on kpc scales jet is confined by a halo of X-ray emitting gas but not on pc scales)

- <u>spine-layer model:</u>
- **Layer:** near to equipartition:
- $L_p \sim 5*10^{43}$ erg s^{-1} $L_B \sim 2*10^{43}$ erg s^{-1}
- **Spine (Γ=15):**
- $L_{kin} \sim 3*10^{44}$ erg s^{-1} $L_r \sim 2*10^{43}$ erg s^{-1}

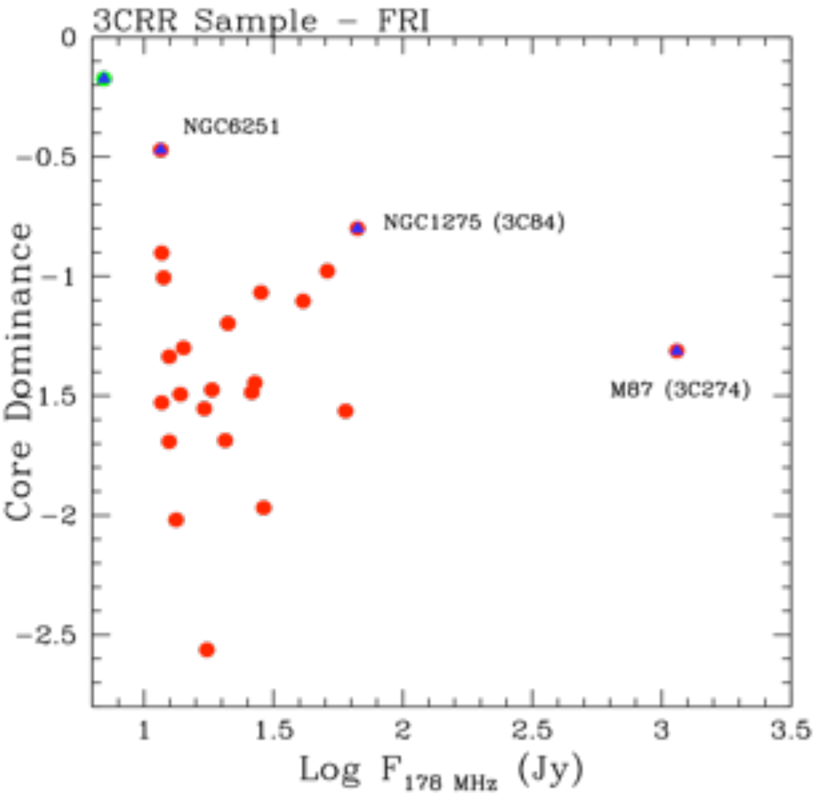
Light and Dissipative Jet

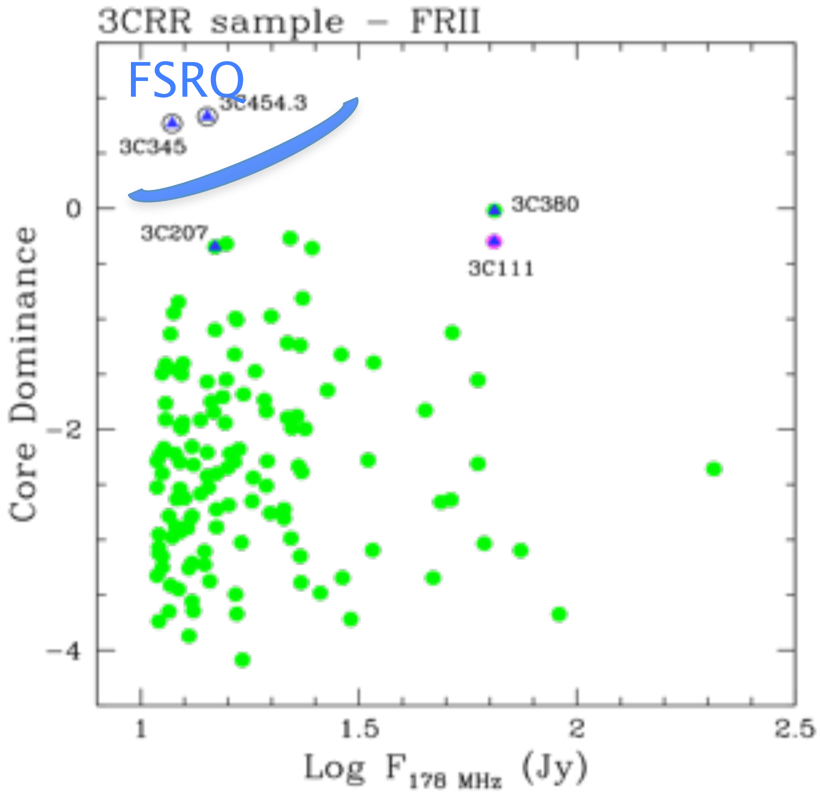
- High radiative losses (~1/3 of the spine kin. energy)

What about FRII sources?

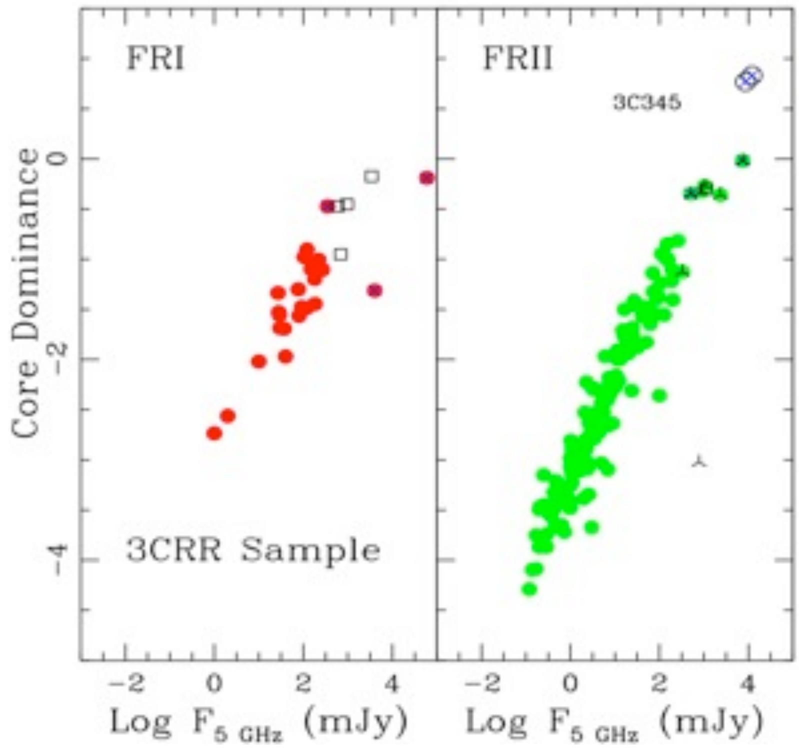
Study of the Core Dominance of the MAGNs belonging to the 3CRR sample

Core Dominance: $R = F_{core}/(F_{tot} - F_{core})$ at 5 GHz





Fainter LAT misaligned AGNs have larger Core Dominances, i.e. smaller jet inclinations



- FRI with large jet inclination angles (i.e. small CDs) can be observed if nearby
- No FRII (seen far away from the jet) has been so far observed by Fermi
- When the distance increases, i.e. the source appears weaker, the sources must have a larger CD in order to be detected at GeV energies

Do we miss FRIIs because they are at larger redshift than FRIs and thus too weak ?

Summary

1. MAGNs sample is mainly populated by local FRI radio galaxies

2. Only a few FRI nearby RGs with wide inclination angles (i.e. small CD parameters) have been detected. Increasing the distance, the CD of the GeV sources tend to increase.

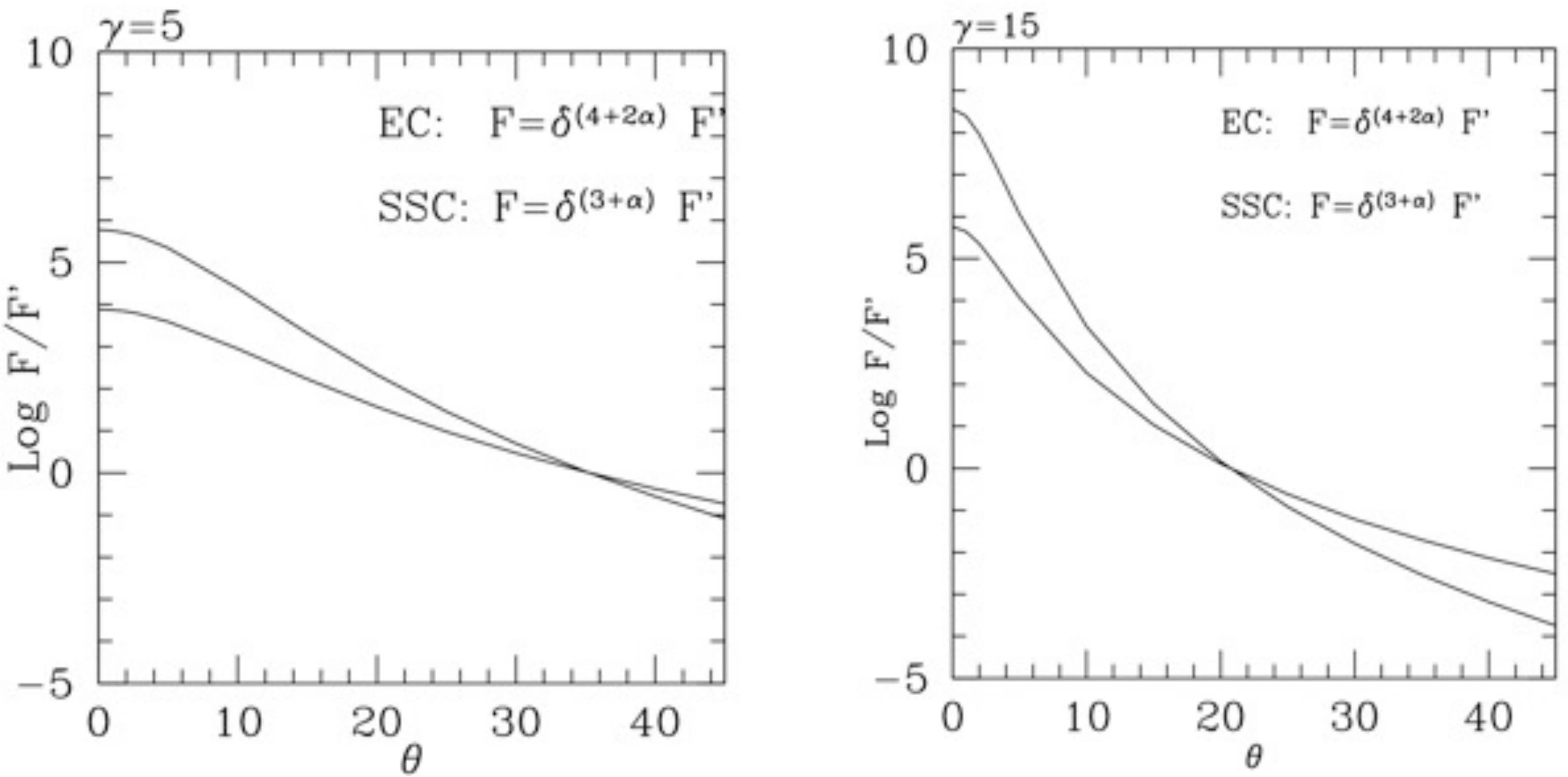
3. In FRIs, GeV photons can be produced by pc-scale jets and/or by giant radio lobes

4. In both cases the Inverse Compton is the physical process responsible for the gamma-ray production (involving external or internal jet photons)

5. The NGC 6251 nuclear SED (but also M87 and NGC 1275) can be fitted with a SSC model but require a slow plasma motion. A spine/layer jet seems an alternative viable solution.

6. The small number of FRIIs with LAT associations could be simply related to their larger redshifts or indicate the presence of less structured jets.

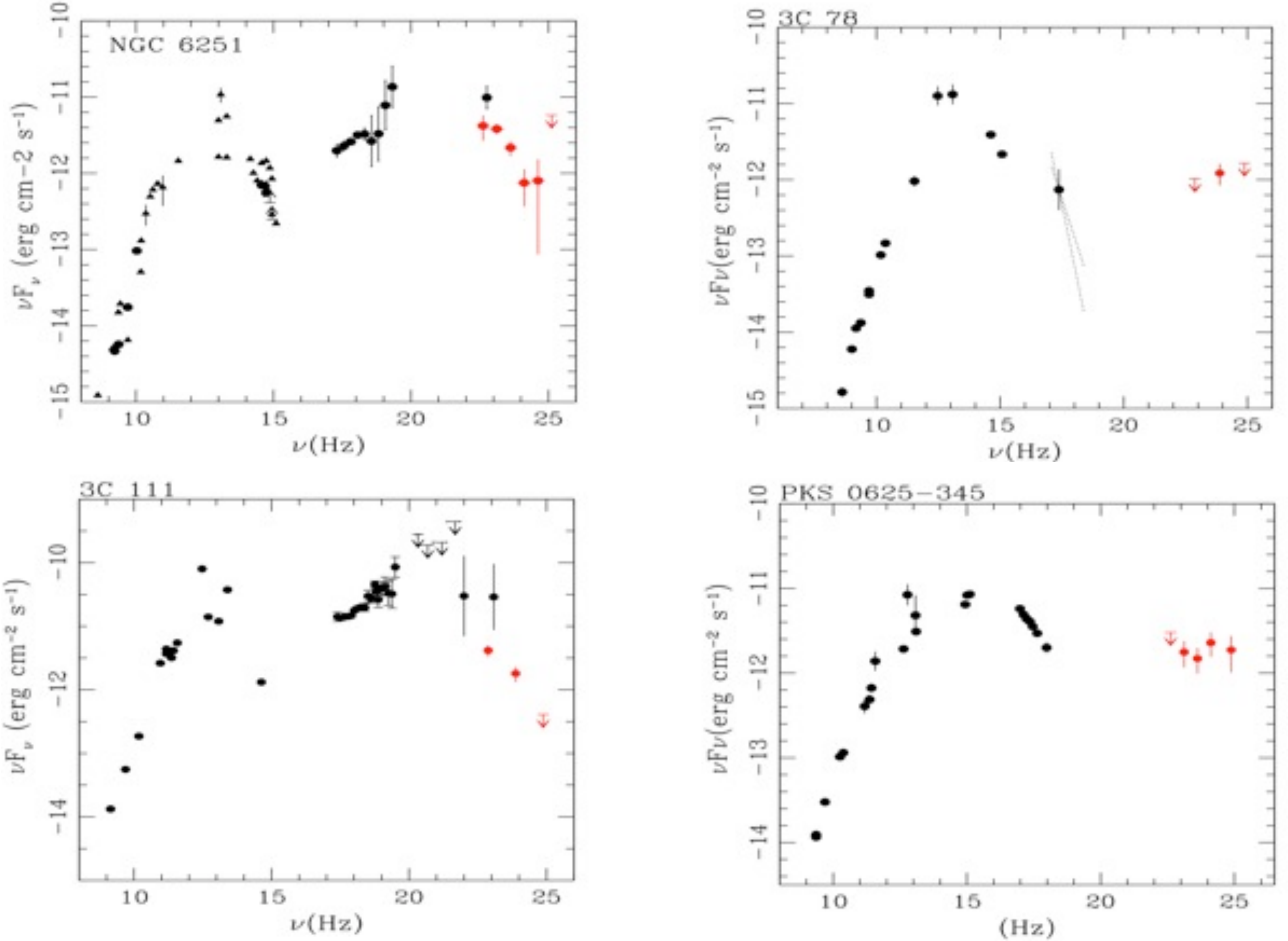
Do SSRQs require a larger beaming that the other MAGNs to be observed at GeV energy?



In FRII the jet propagates through a photon rich environment => EC dominant mechanism

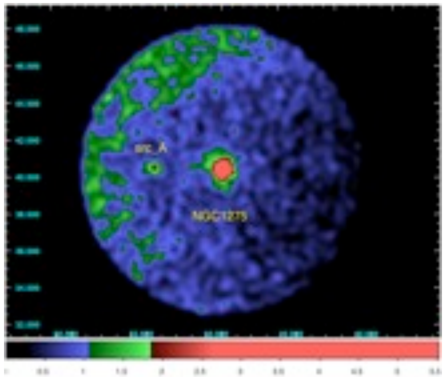
EC emission is narrower in the beaming direction than the beaming pattern of SSC

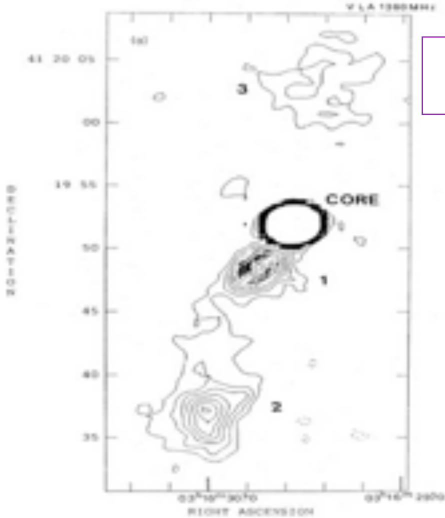
Spectral Energy Distribution



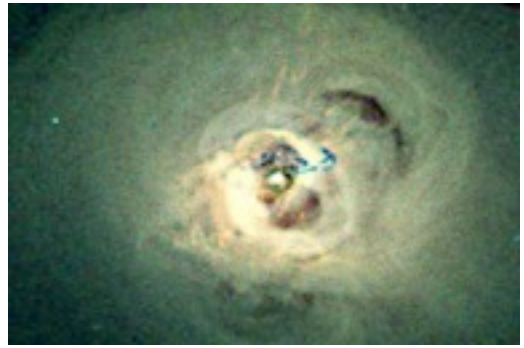
NGC1275

Abdo, A. et al. 2009, ApJ, 699, 31





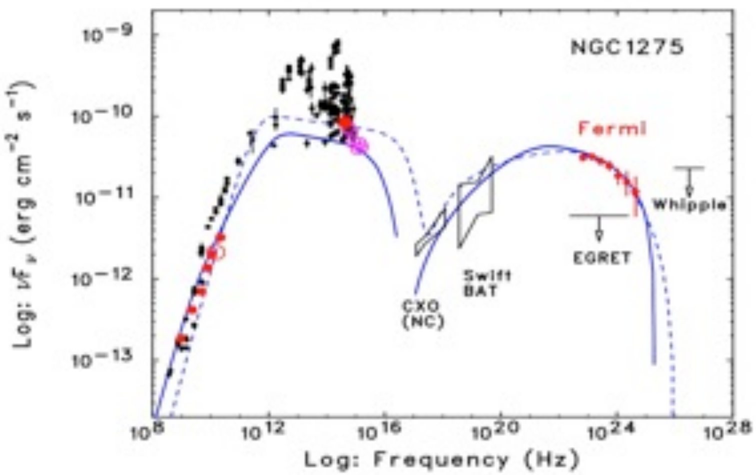
FRI in the center of the Perseus Cluster



One simple zone SSC model

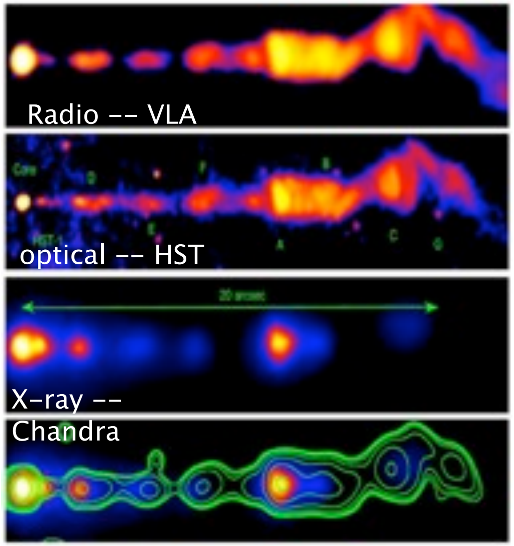
γ=1.8 δ=2.3 θ=25°
B=0.05 G R=2×10^{18} cm
$n=\varepsilon^{-p}$ p=2.1 800 $\leq \varepsilon \leq$960 p=3.1 960< $\varepsilon \leq 4\times10^{5}$
P_{jet} ~ 10^{44} erg sec^{-1}

gamma-rays produced by pc-scale jet



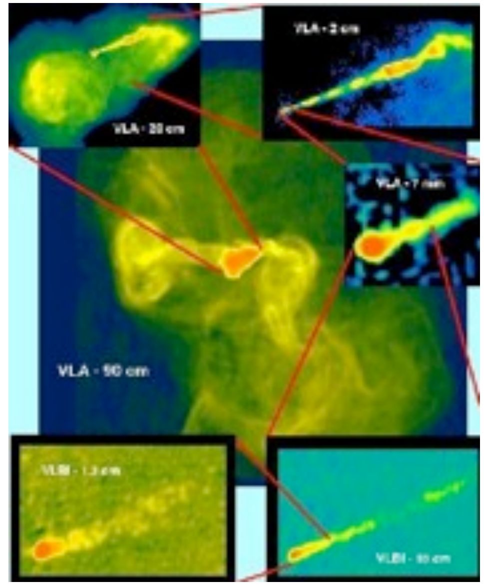
Decelerating flow

γ_{max}= 10 γ_{min}=2 Δ R= 5×10^{17} cm B= 0.2 G θ = 20° U_p= 13 U_B
$n=\varepsilon^{-p}$ p=1.8 800 $\leq \varepsilon \leq 1.0\times10^{5}$
P_{jet} ~ 6×10^{43} 5×10^{44} erg sec^{-1}

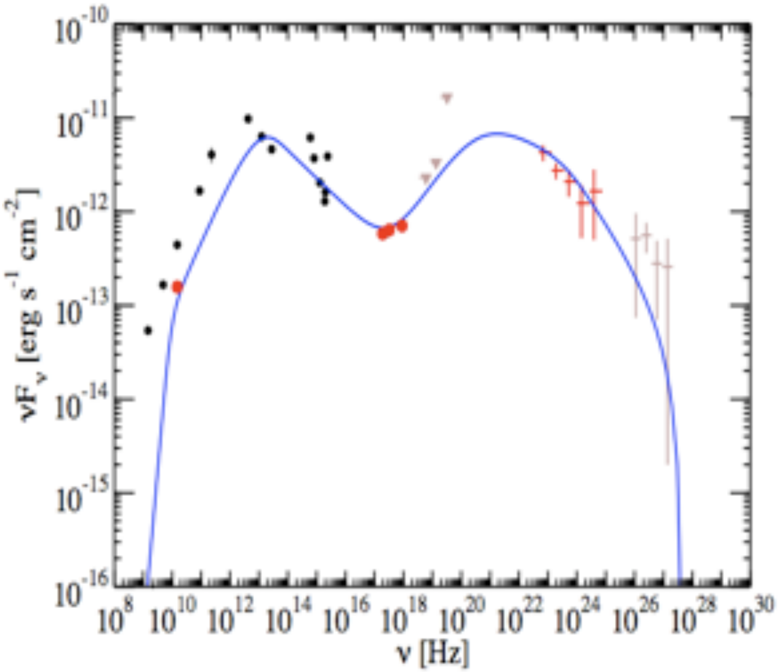


M87

Abdo, A. et al. 2009, ApJ, 707, 55



M87 is in Virgo cluster. FRI RG
Jet sub-structures resolved in radio, optical (4c-6c) and X-ray (θ~20°).
TeV (>350 GeV): flux variation Δt~1 day



SSC one zone model

Emission from sub-parsec scale jet (core) as suggested by 2008 VHE Chandra VLBA monitoring

θ=10° Υ =2.3 δ =3.9

n = $k\varepsilon^{-p}$ p=1.6 [1, 4x10^3] p=3.6 [4x10^3, 10^7]

R=1.4x10^{16} cm

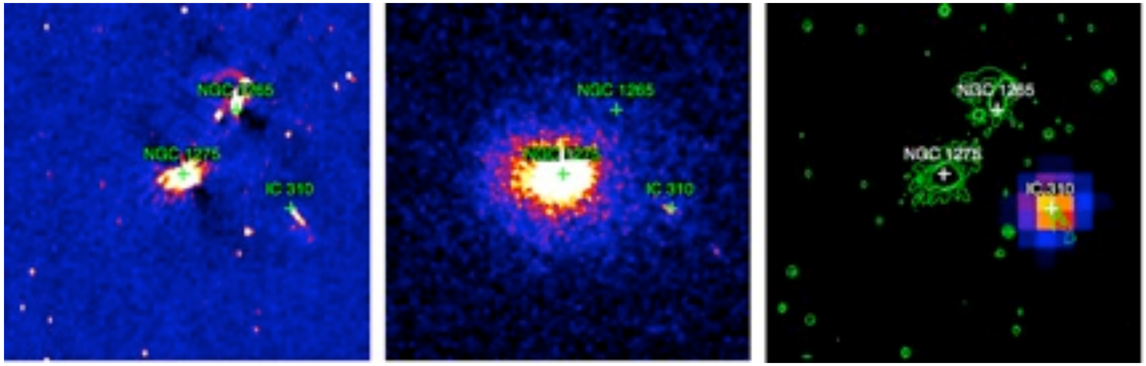
B=55 mG

At optical, ultra-violet, and near-infrared wavelengths, the EBL is thought to consist mainly of starlight from unresolved galaxies at a range of redshifts, with possible additional contributions from stars or gas in intergalactic space, and from decaying elementary particles. In the mid- and far-infrared, the main contribution is thought to be redshifted emission from dust particles, heated by starlight in galaxies

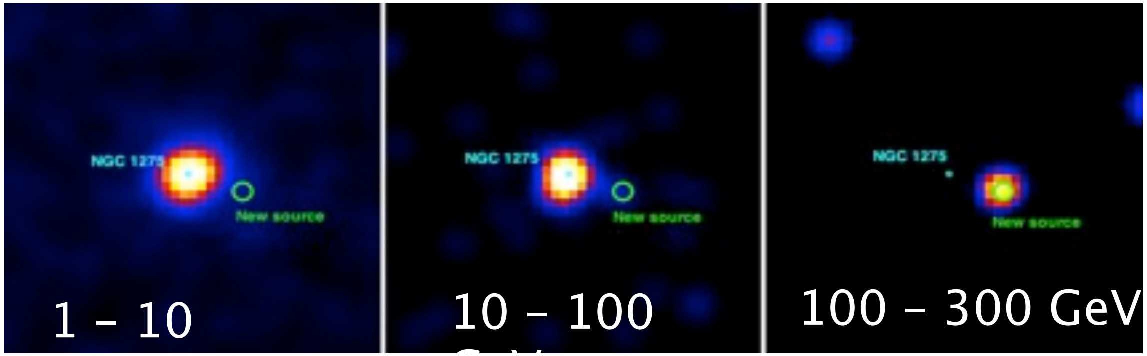
The optical emission is more concentrated in the knots and along the center line of the jet (Sparks, Biretta, & Macchetto 1996 ; Biretta et al. 1999a) VLA and HST polarimetry, which show that the radio and optical emission must arise in somewhat separate regions with di†erent magnetic Ðeld conÐgurations (Perlman et al. 1999).

A direct consequence of such a structure is that while at small viewing angle (as in the case of blazars) the emission is dominated by the boosted spine emission, at large observing angles ($\theta > 45^{\circ}$, typical for radio-galaxies) the emission from the spine would be suppressed, while the layer, characterised by a broader beaming cone, could substantially contribute to (and sometimes dominate) the overall emission. At intermediate angles both components can significantly contribute.

Head-Tail Radio Galaxy IC 310: a new class of gamma-ray emitter ?



IC 310 has an extended tail of the angular size 15′ aligned along the direction connecting the center of Perseus



ATel #2510; Mose Mariotti, on behalf of the MAGIC collaboration
An analysis of 38 hours of single telescope observations performed from 2008 to 2010 has confirmed the detection at ~6 sigma significance. Preliminary analysis indicates emission at the level of ~2.5% of the Crab Nebula flux above 300 GeV.

Gamma-ray are produced at the shock formed in interaction of relativistic outflow from the fast moving galaxy with the inter-cluster medium.

Neronov, Semikoz Vovk, 2010 arXiv:1003.4615