# Exploring the FRI/FRII radio dichotomy with the Fermi satellite

Fermi and Jansky: Our Evolving Understanding of AGN

November 10-12, 2011
Harbourtowne Conference Center
St Michaels, MD, USA

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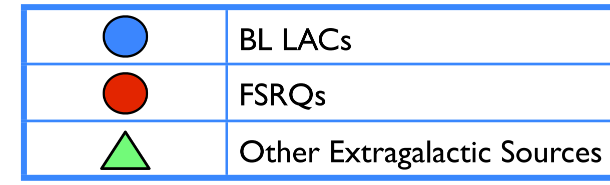
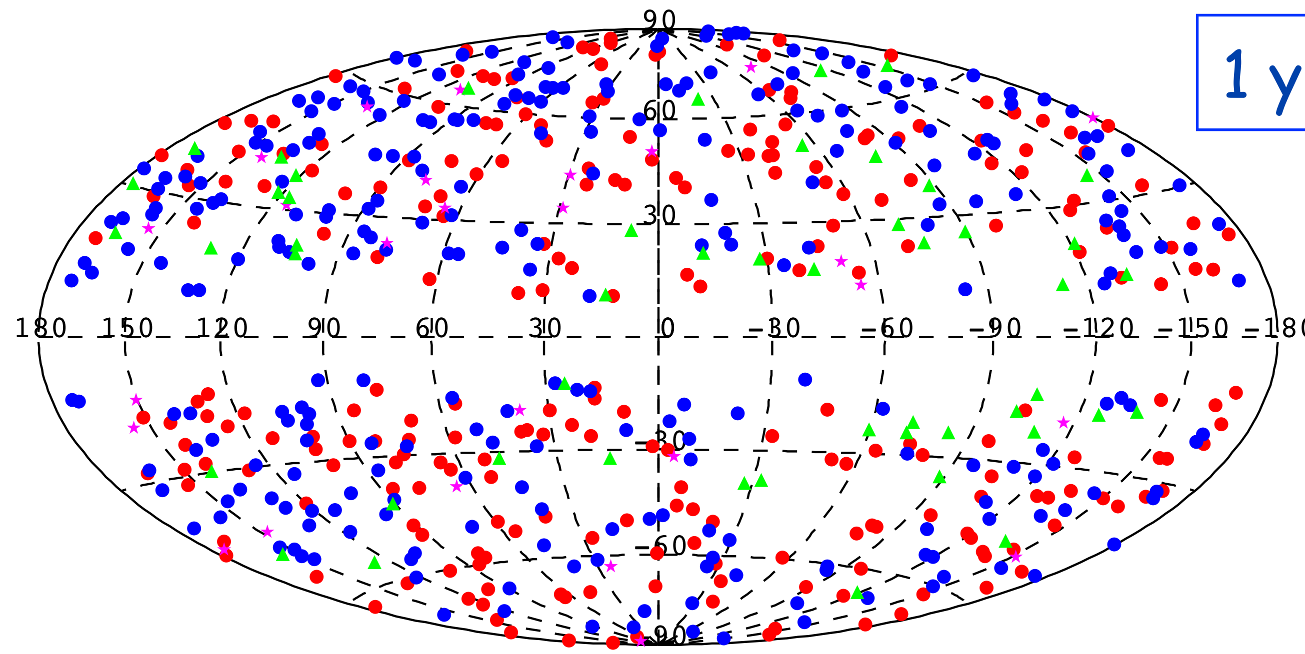
Fermi Gamma-ray Space Telescope

# The Fermi sky

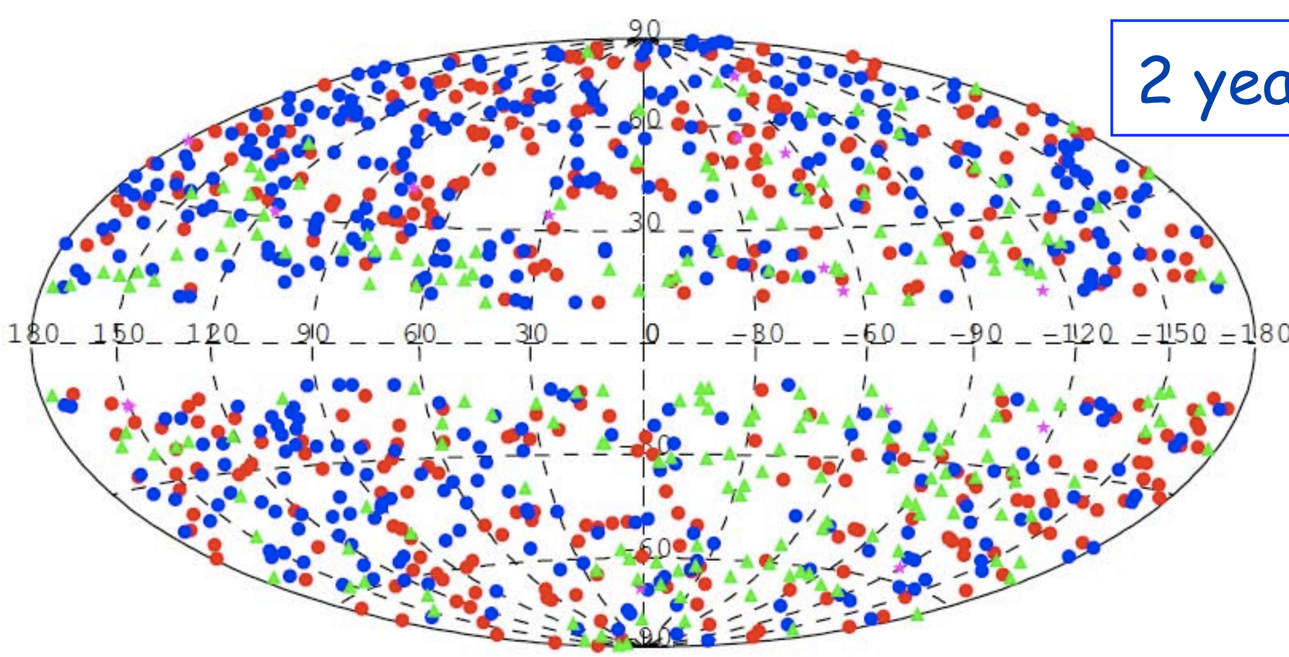



The clean sample of the First Catalog of AGN (1LAC) contains 599 sources

Abdo, A. A., et al. 2010a, ApJ, 715, 429 (1LAC);
Abdo, A. A., et al. 2010b, ApJS, 188, 405 (1FGL)




1 year

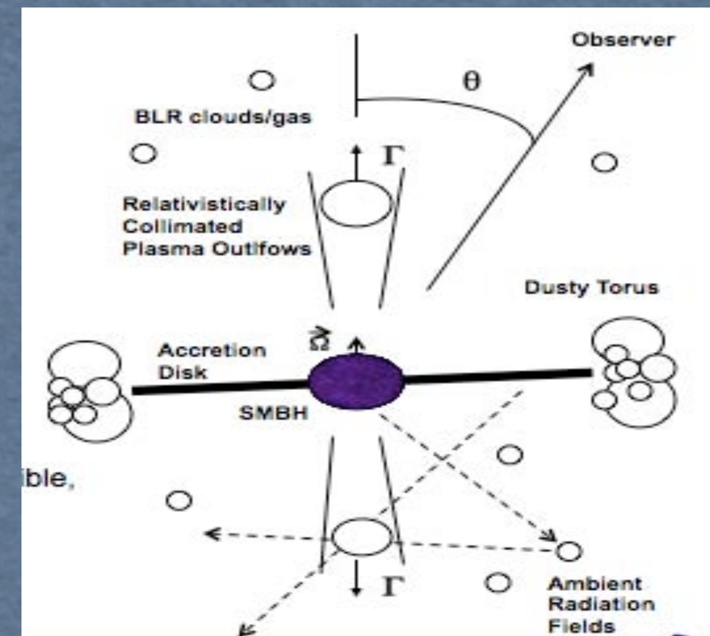



2 years

In the Second Catalog of AGN (2LAC-ApJ in press), the number of detected AGNs is increased by more than 40% (877 sources).

# The majority of Extragalactic Sources are BL LAC and FSRQs

$\delta = 1/\Gamma(1-\beta \cos\theta)$




The Doppler factor relates intrinsic and observed flux for a moving source at relativistic speed $v=\beta c$.

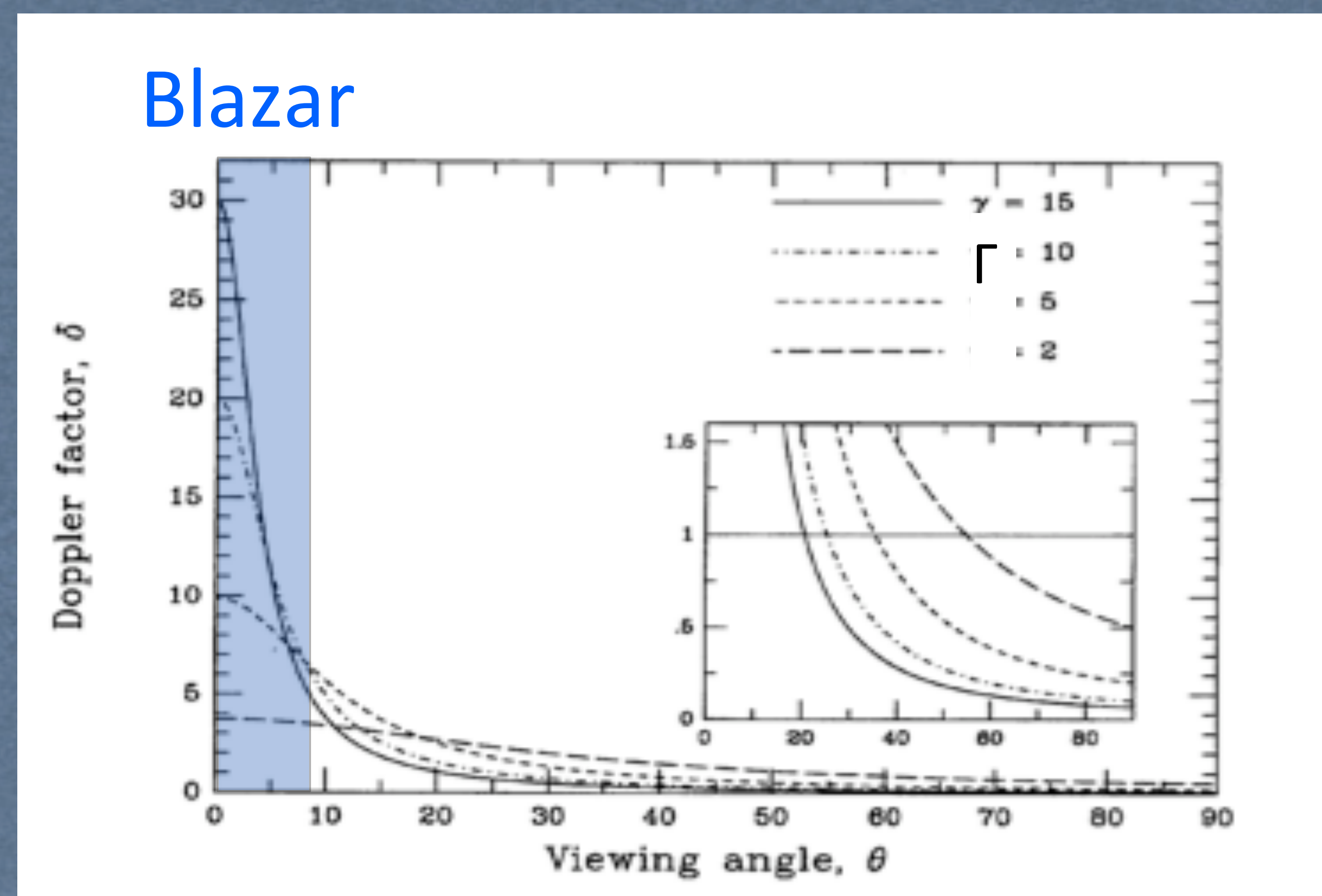
For an **intrinsic** power law spectrum:

$F'(\nu') = K (v')^{-a}$

the **observed** flux density is

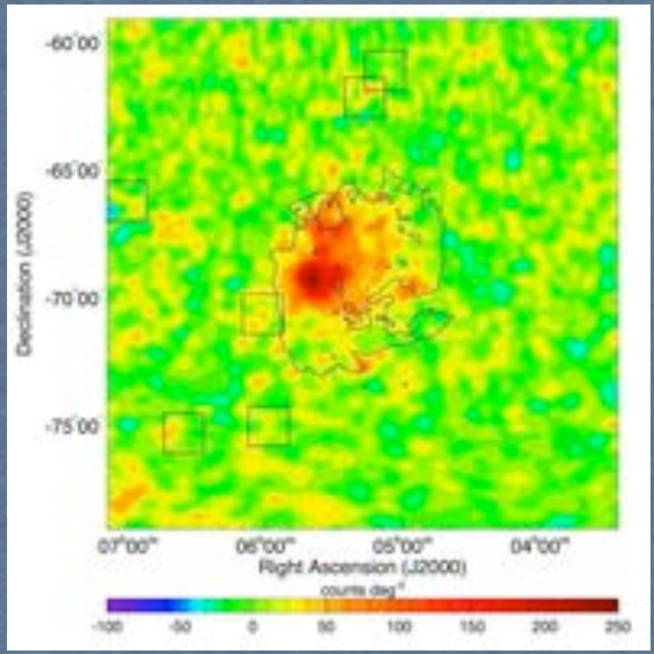
$F_{\nu}(\nu) = \delta^{p} F'_{\nu'}(\nu)$

$p=n+\alpha$



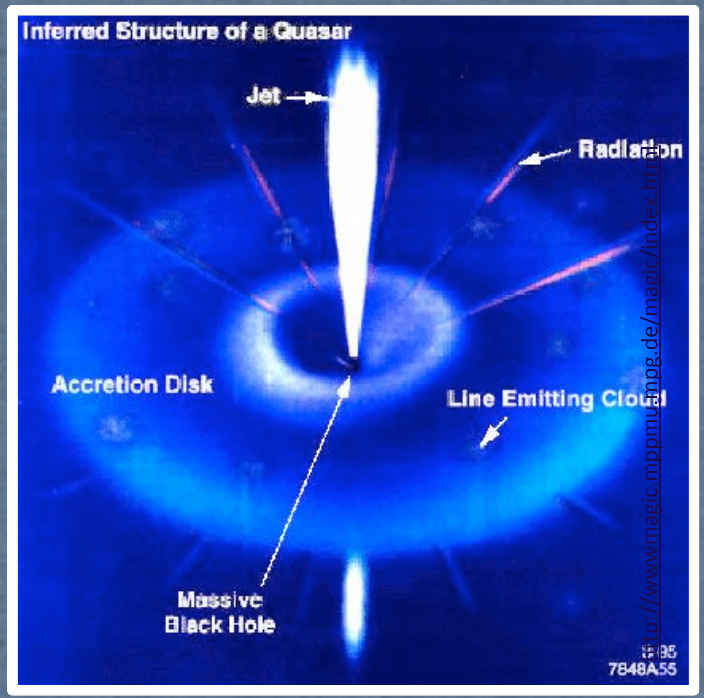
## However ~3% of the $\gamma$-sources are not Blazars

The "other" Extragalactic Sources belongs to two broad classes of objects reflecting two different particles acceleration processes:




1. SNR as particle accelerator -- SNR expanding shocks -> CR acceleration -> $\gamma$-rays

<u>Starburst Galaxies</u>

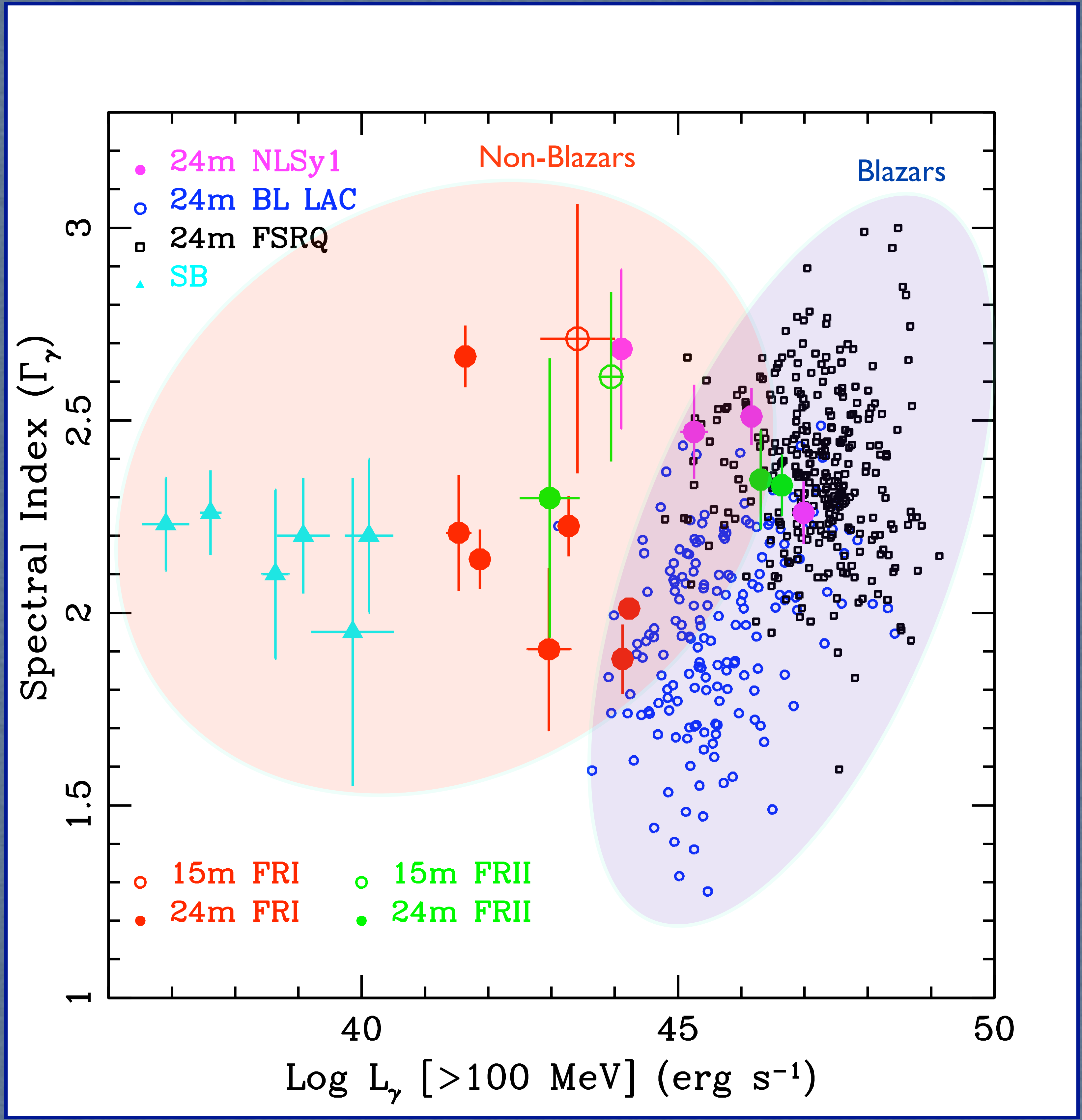



2. AGN as particle accelerator -> Jets

<u>Narrow Line Seyfert 1 Sources</u>

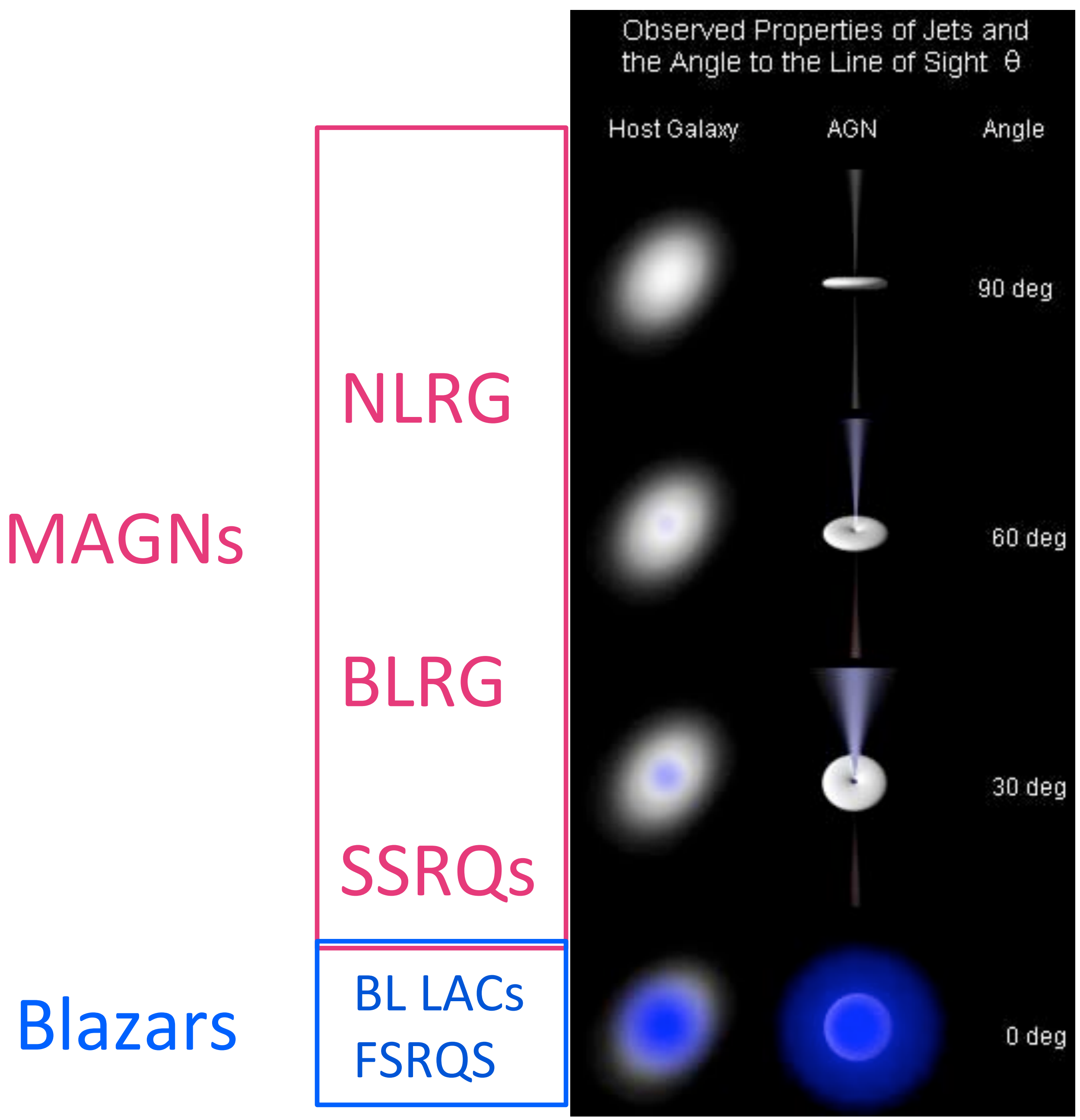
Misaligned AGNs

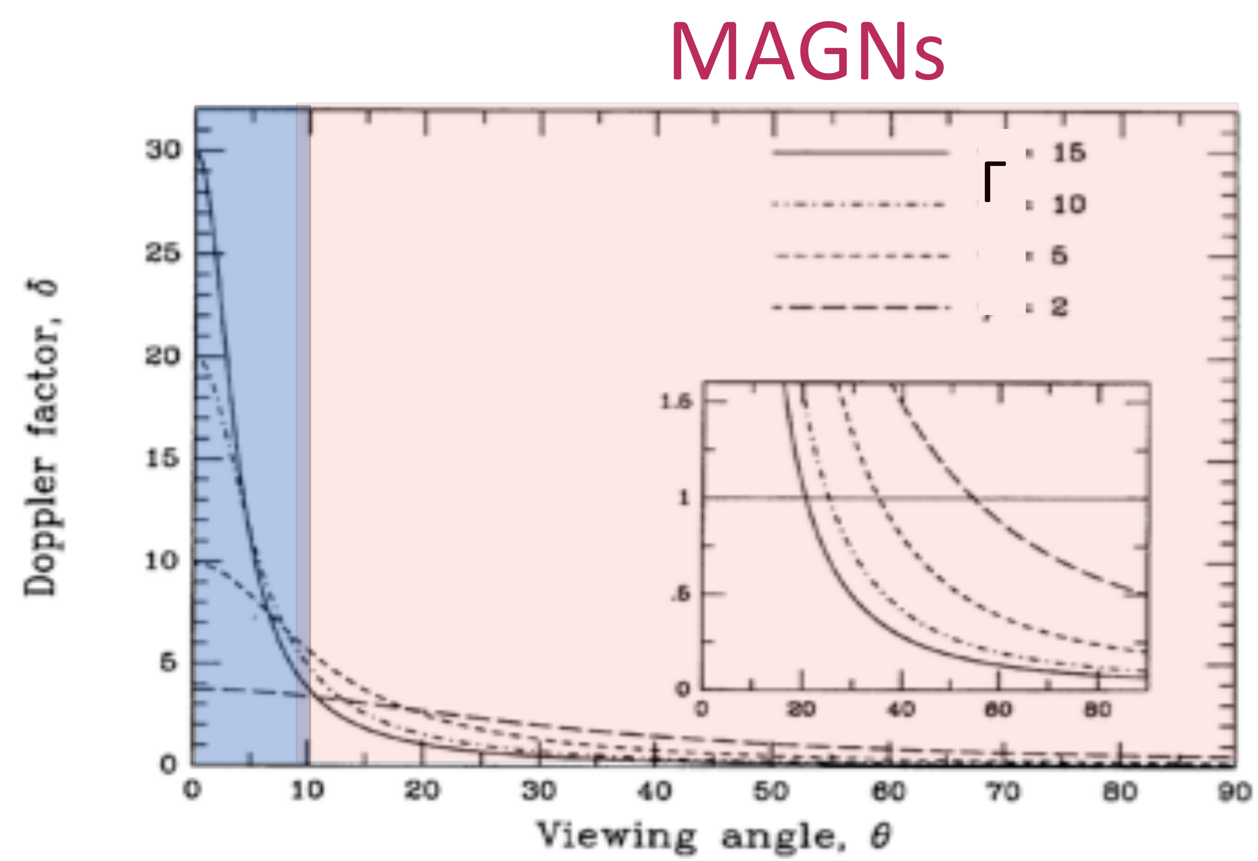
# After 24 months of sky survey



# 2. AGN as particle accelerator: Misaligned AGN (MAGN)

With MAGNs we intend Radio Sources with the jet not directly pointed towards the observer.



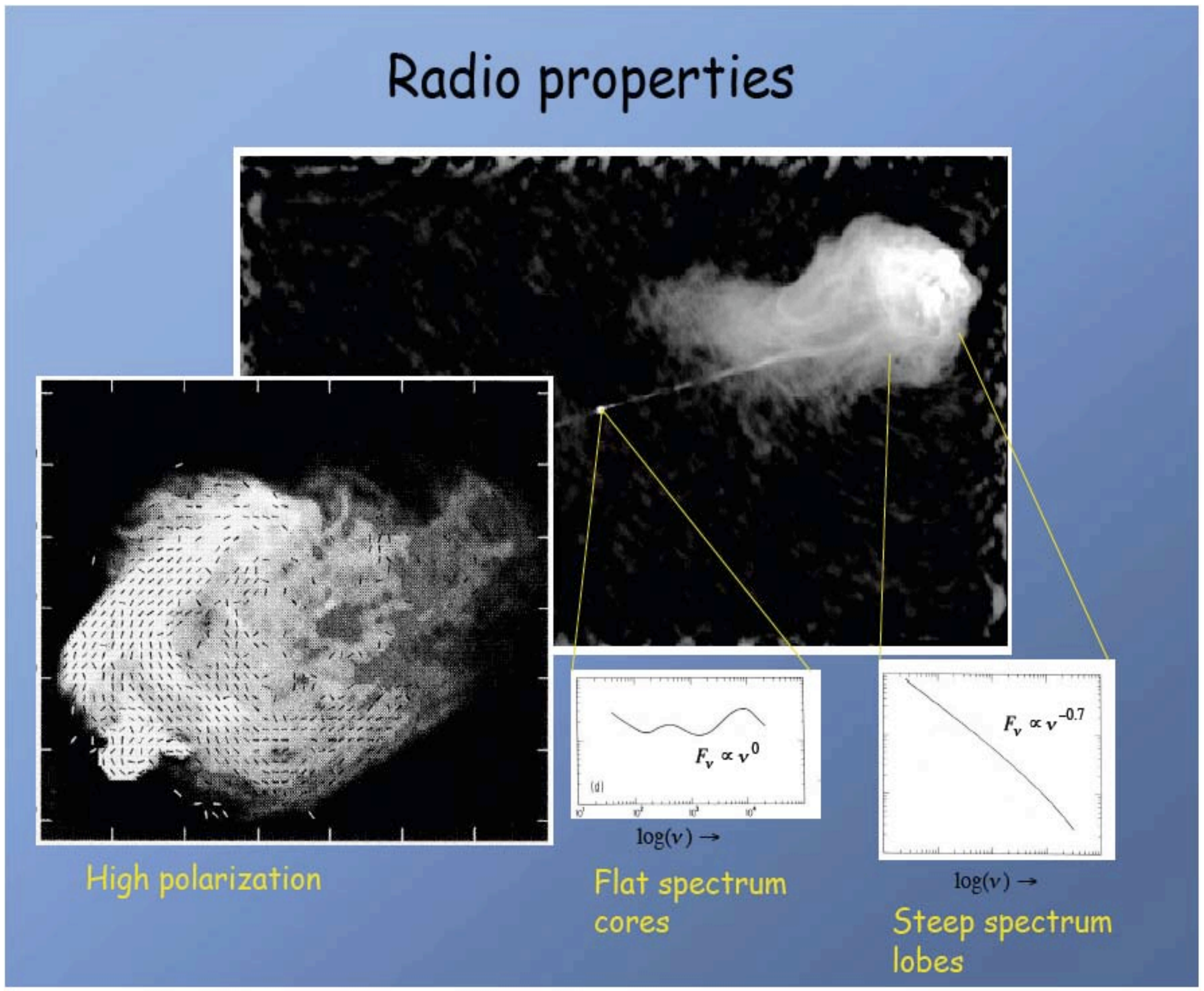



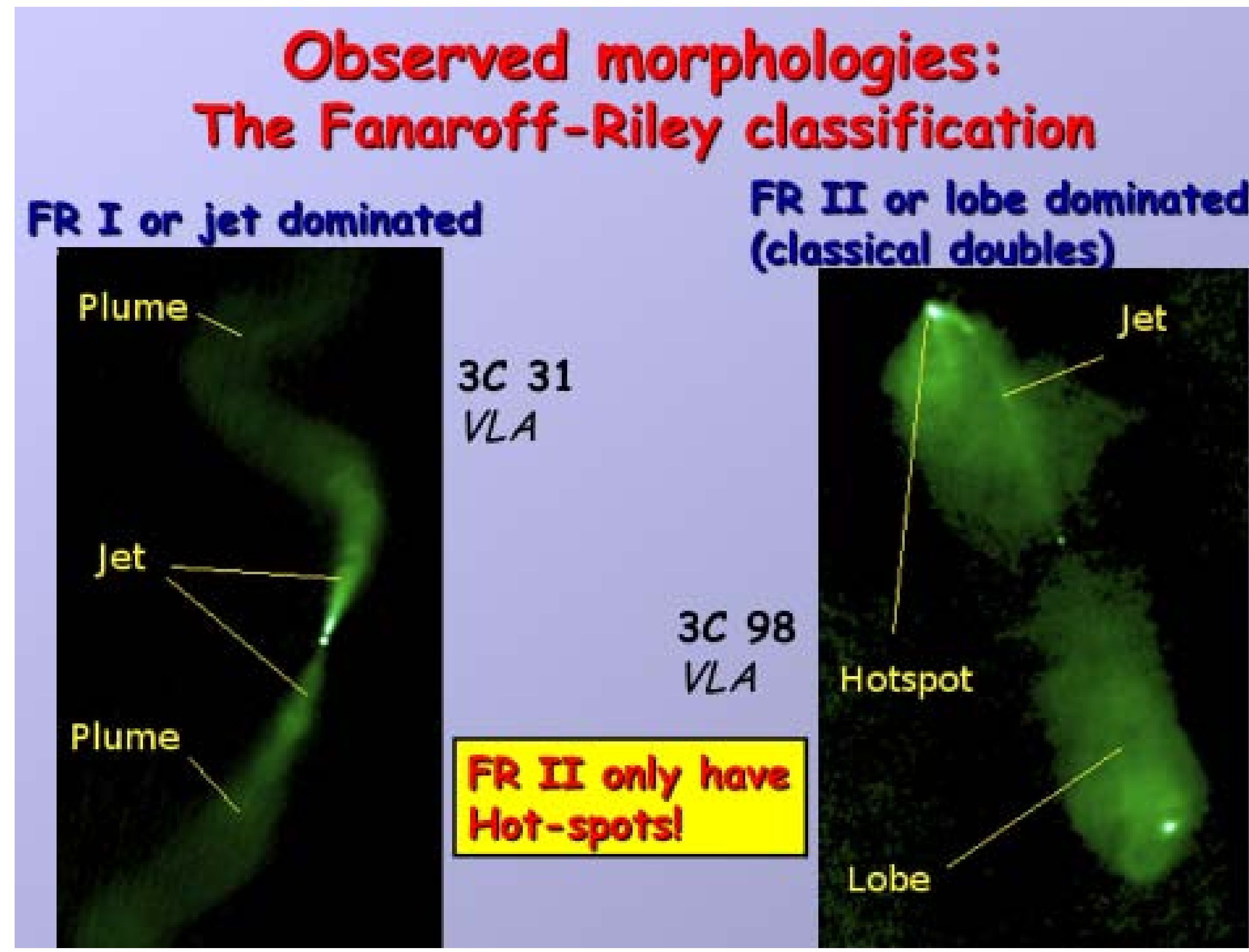
# MAGNs show:

Steep Radio Spectra
$\alpha$ >0.5

and/or

Resolved and possibly symmetrical structures in radio map




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

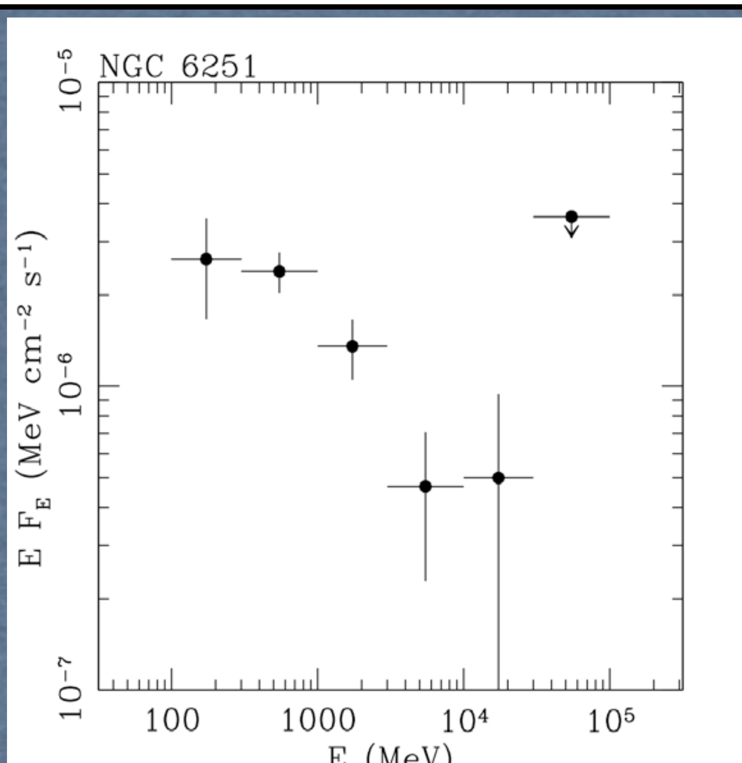
However the picture could be more complex (see Kharb, Lister and Cooper ApJ 2010)

# FIRST SAMPLE of MAGNS (15 MONTH-DATA)

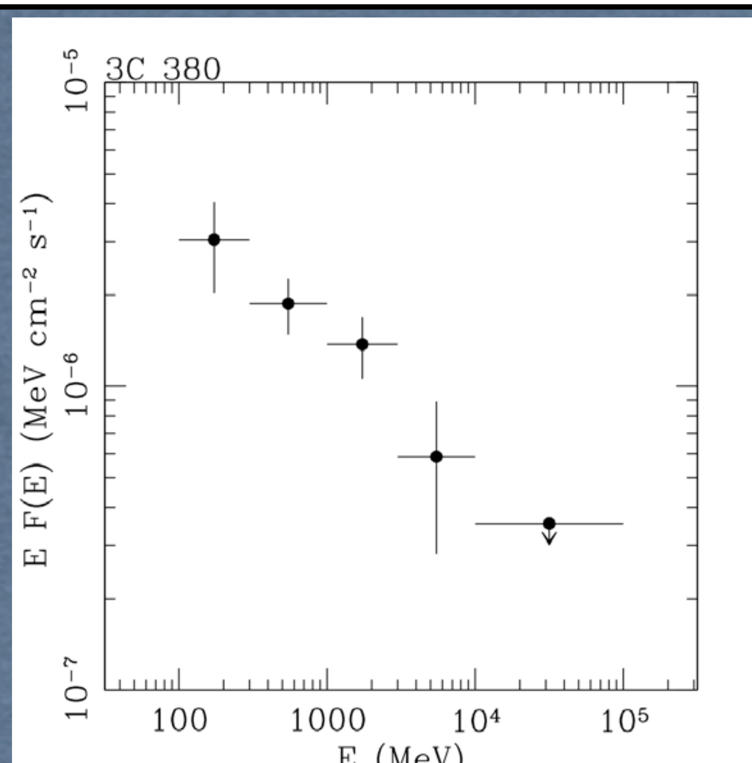
Table 1: The Sample

| 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 |

Abdo, A. A., et al. 2010, ApJ, 720, 912 (MAGN)




FR I Radio Galaxy




FRII SSRQ

MAGNs are generally faint and soft sources

F(>0.1 GeV)~$10^{-8}$ Phot. $cm^{-1}$ $s^{-2}$
$\Gamma \sim 2.4$

The association of MAGNs to $\gamma$-ray LAT sources has raised some questions:

First question

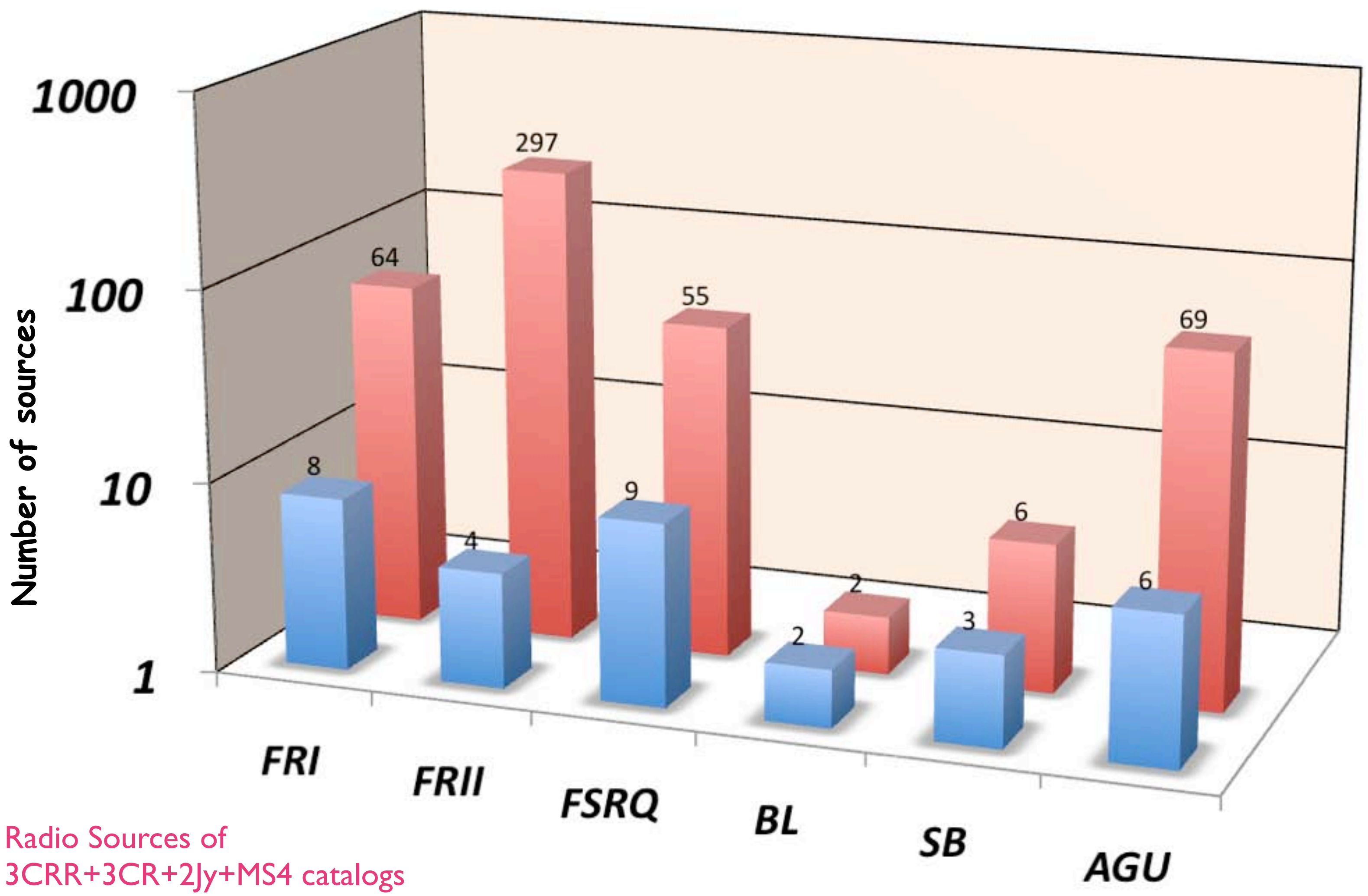
Are we really missing FRII radio galaxies?

3CRR sample $\nu$ =178 MHz
F> 10.9 Jy
173 sources

3CR sample $\nu$ =178 MHz
F> 9 Jy
113 sources

2Jy sample $\nu$ =2.7 GHz
F> 2 Jy
88 sources

Molonglo Southern 4Jy sample MS4 $\nu$ =408 MHz
F> 4 Jy
228 sources



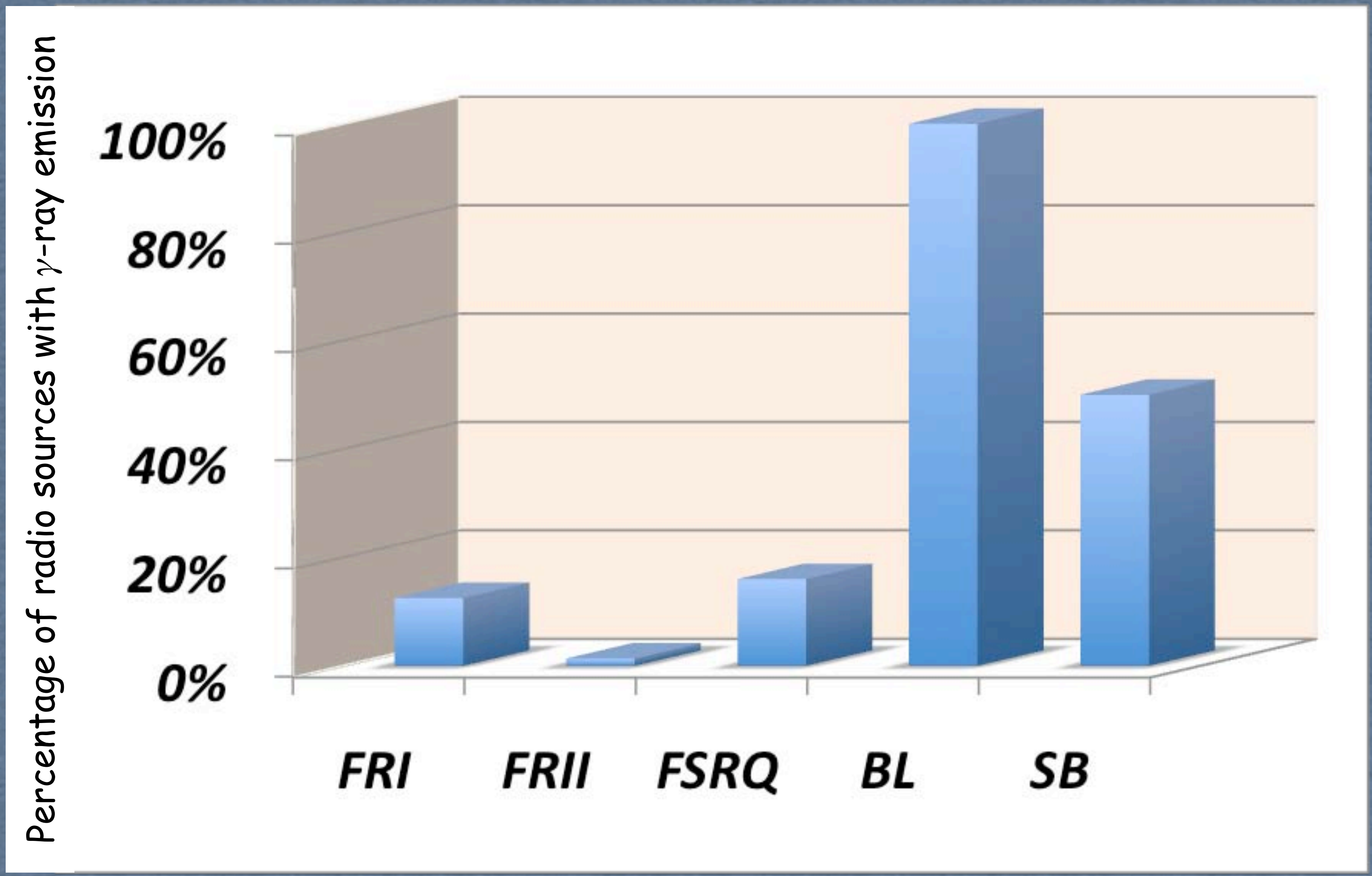

Radio Sources of
3CRR+3CR+2Jy+MS4 catalogs

Radio Sources of
3CRR+3CR+2Jy+MS4 catalogs
with LAT association

# Rate of Detections for each class

Source with TS >25

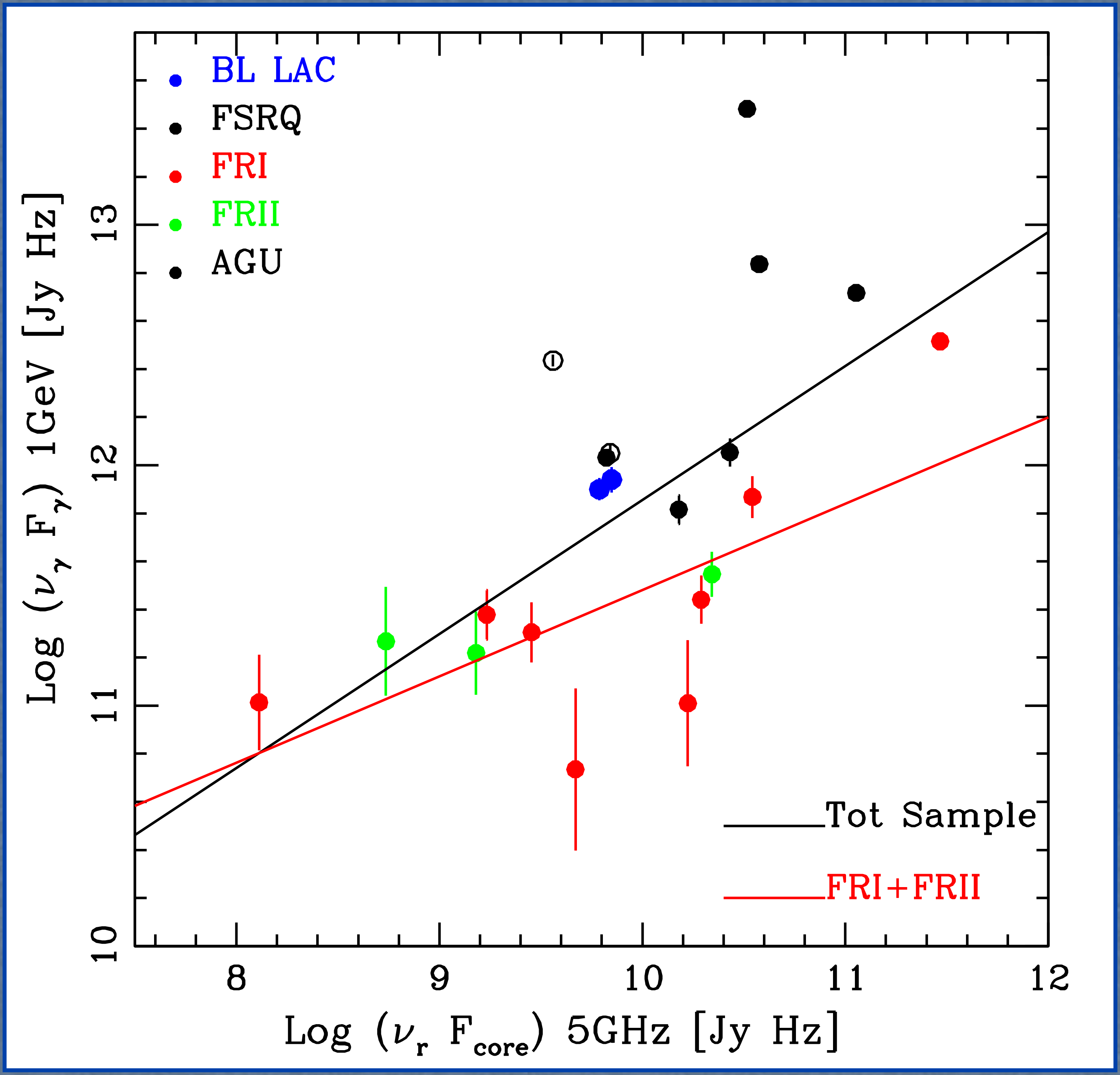
15 and 24 months of sky survey




**FRII are the less detected objects**

The $\gamma$-ray elusiveness of FRIIs has been also confirmed by a dedicated study of Broad Line Radio Galaxies (Kataoka et al. 2011)

# Are FRIIs elusive GeV sources because too far? Maybe not!



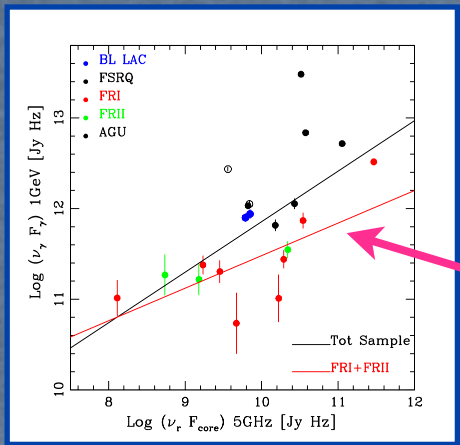

$$\text{Log } (f\,\nu)_{1GeV} = a + b \times \text{Log}(f\,\nu)_{5GHz}$$

| | a | b | r | P_r |
|---|---|---|---|---|
| TOT | 5.1 (1.0) | 0.7 (0.1) | 0.74 | >99.9% |
| **TOT** TS>25 | 6.2 (1.6) | 0.6 (0.2) | 0.65 | 99.9% |
| MAGN TS>25 | 7.9 (1.2) | 0.4 (0.1) | 0.66 | 97.4% |

The Radio $\gamma-$ray fluxes are correlated

see also: Ghilranda et al. 2011, Ackermann et al. 2011 ApJ in press

# Predicted fluxes @ 1 GeV of the 3CR+3CRR+MS4+2Jy sources

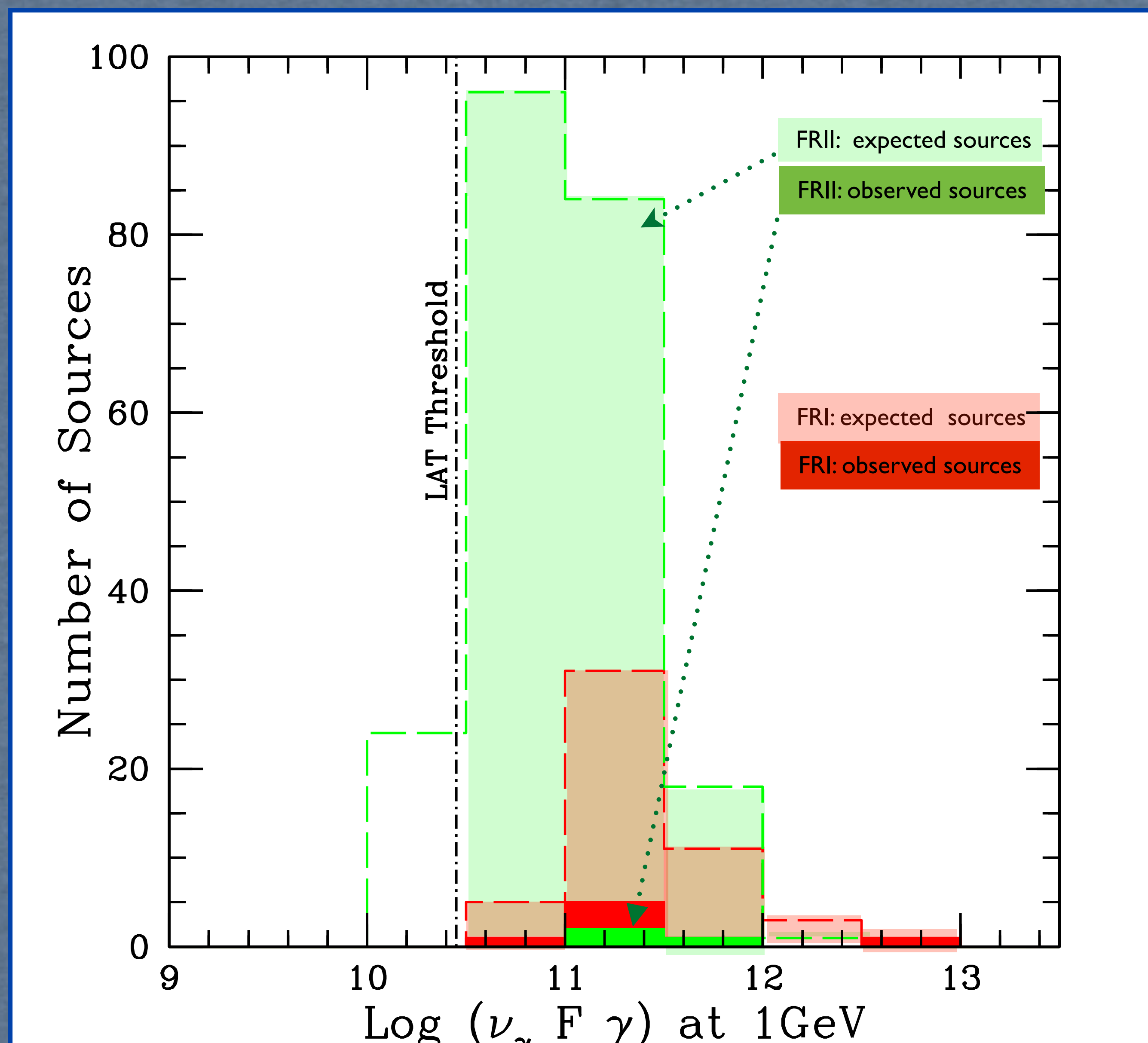



$$\text{Log}(f\,\nu)_{1GeV} = a + b \times \text{Log}(f\,\nu)_{5GHz}$$

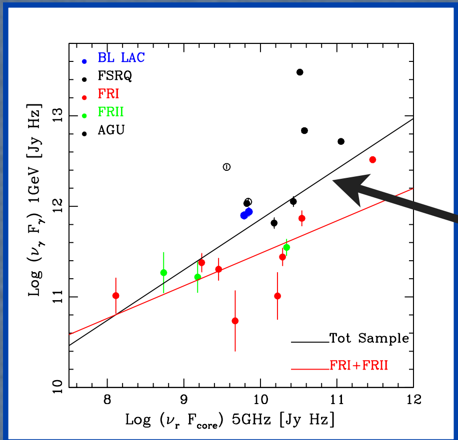
Predicted

Observed

correlation based on the MAGN sample



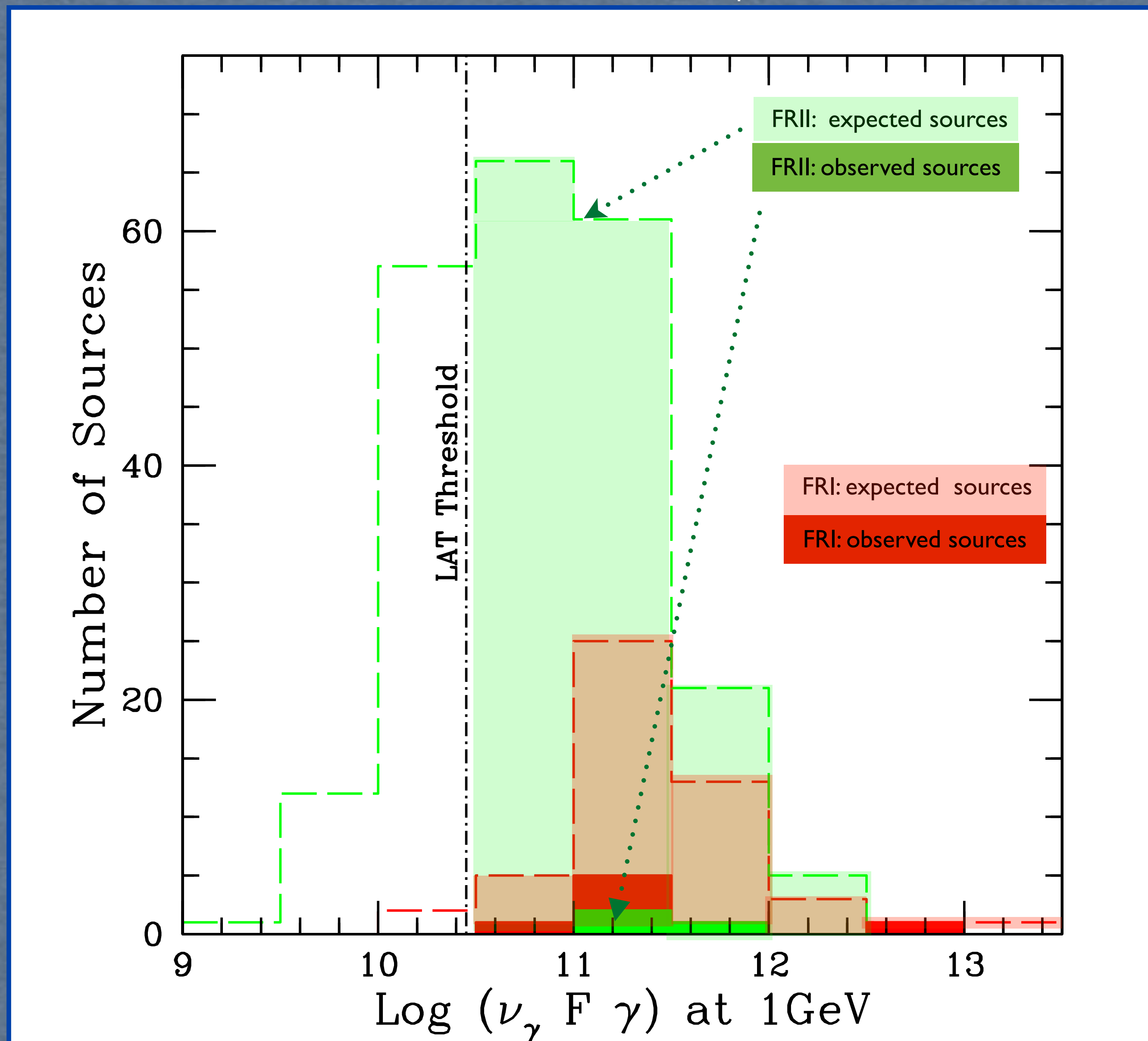
# Predicted fluxes @ 1 GeV of the 3CR+3CRR+MS4+2Jy sources




$$\text{Log}(f\,\nu)_{1GeV} = a + b \times \text{Log}(f\,\nu)_{5GHz}$$

Predicted — Observed

correlation based on the total sample




A large number of FRIIs should cross over the LAT sensitivity threshold.
In spite of this, only a handful of FRIIs is seen at GeV energies ( see also Dermer & Benoit 2011)

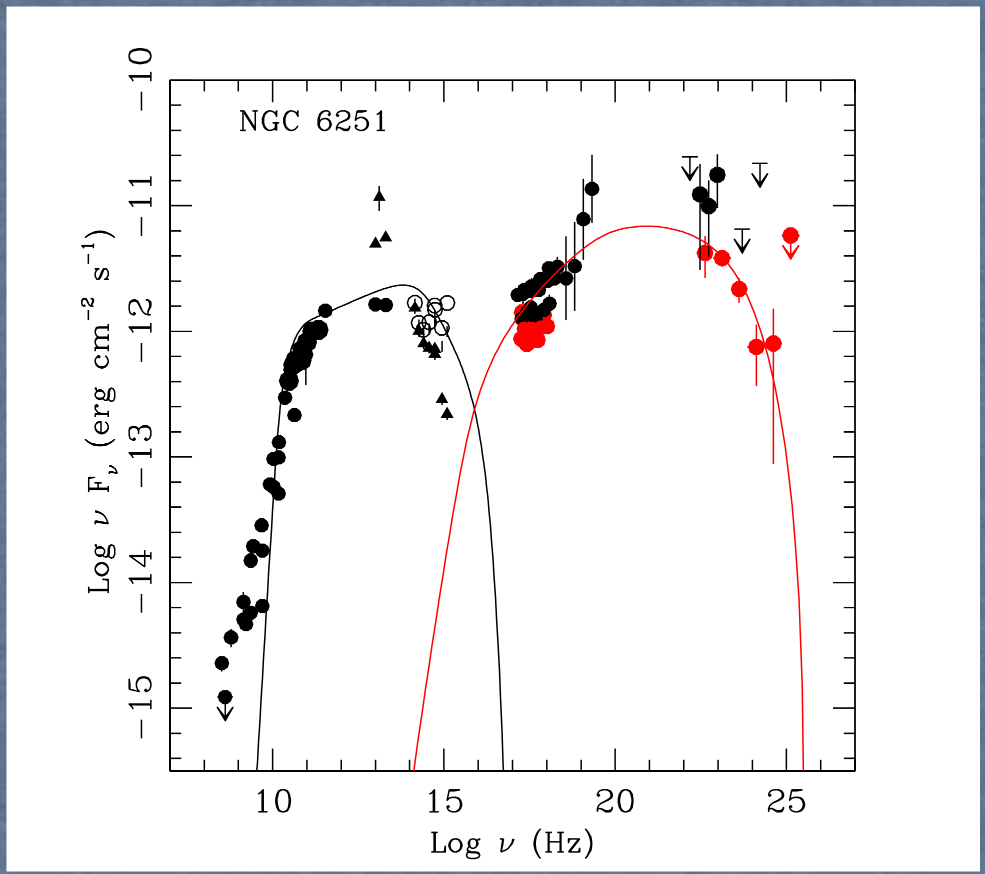
Radio Flux indicates that the “core” of FRIIs is bright enough to be visible at very high energies

Second question

Why does Fermi-LAT preferentially catch FRIs and lose FRIIs ?

SED studies of FRI Radio galaxies indicate that
a pure, one-zone homogeneous, synchrotron self-Compton model is problematic

**NGC6251: an example (Migliori et al. 2011)**




Slow SSC jets are also required in other MAGNs
(M87:Abdo et al. 2009; NGC1275: Abdo et al. 2009)

**Model Parameters:**

$\Theta=25°$ $\Gamma=2.4$

$R \sim 10^{17}$ cm  $B \sim 0.04$ G

$N=K\gamma^{-p}$  $p_1=2.76$  $p_2=4.04$  $K \sim 2\times10^{6}$ cm$^{-3}$

$\gamma_{break}=2\times10^{4}$  $\gamma_{min}=250$  $\gamma_{max}=2\times10^{5}$

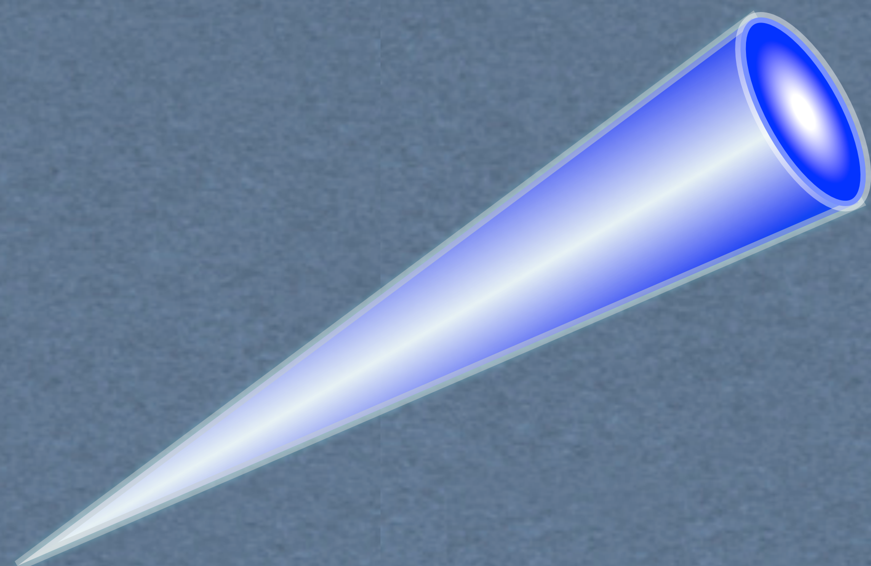
The one-zone homogeneous SSC model applied to MAGNs needs too slow jets

$$\Gamma_{BL} > \Gamma_{MAGN}$$

Possible conflict with Unified Models

Possible solutions to the problems (not the only ones)

- Decelerating jet (Georganopoulos & Kazanas 2003)
- Structured (spine +slower layers) jet (Ghisellini, Tavecchio & Chiaberge 2005)
- Colliding shells (Bottcher & Dermer 2010)



The jet is structured

The hypothesis of homogeneity is relaxed and more regions at different velocities are assumed.

These models can generally fit pretty well the SEDs of FRI radio galaxies.

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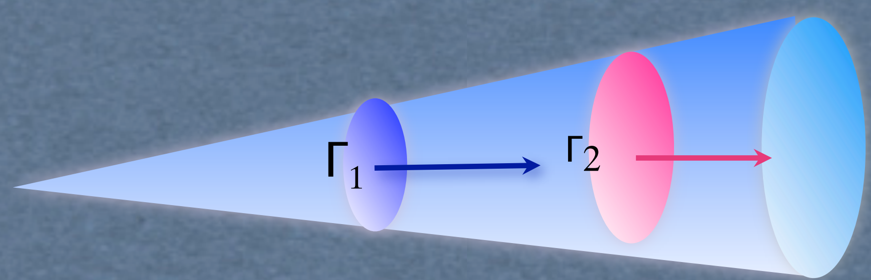


The hypothesis of homogeneity is relaxed and more regions at different velocities are assumed.

The jet is decelerated

These models can generally fit pretty well the SEDs of FRI radio galaxies.

Possible solutions to the problems (not the only ones)

- Decelerating jet (Georganopoulos & Kazanas 2003)
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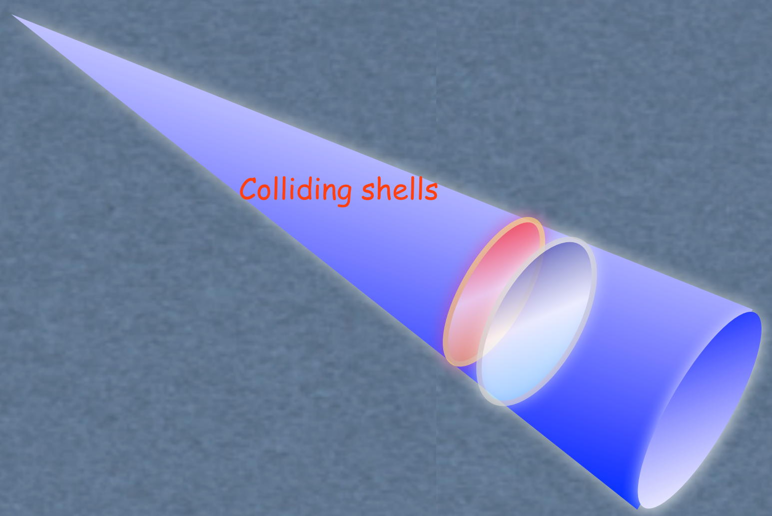
- Colliding shells (Bo"ttcher & Dermer 2010)

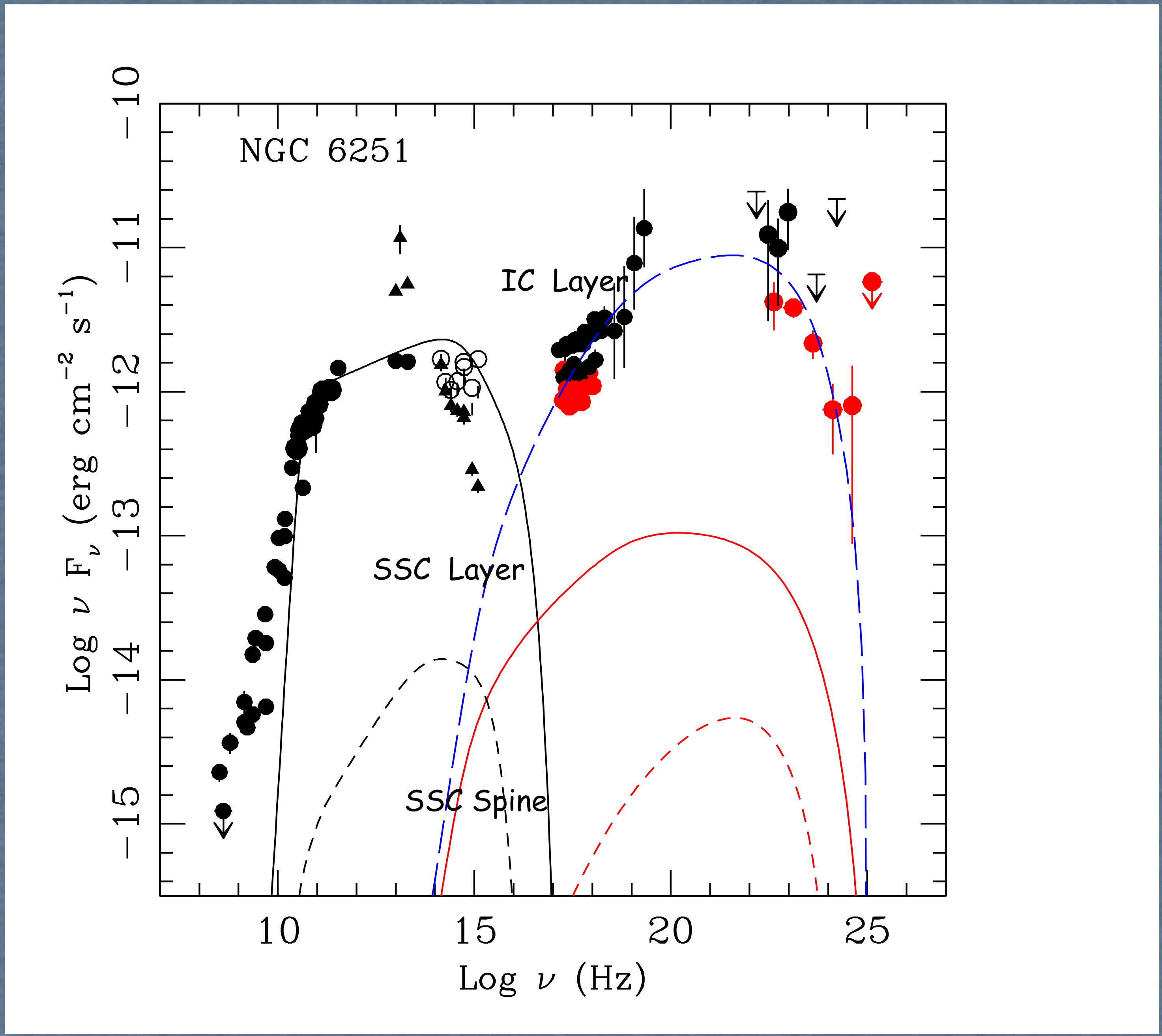



The jet is shocked

The hypothesis of homogeneity is relaxed and more regions at different velocities are assumed.

These models can generally fit pretty well the SEDs of FRI radio galaxies.

(Migliori et al. 2011)




**Structured Jet**

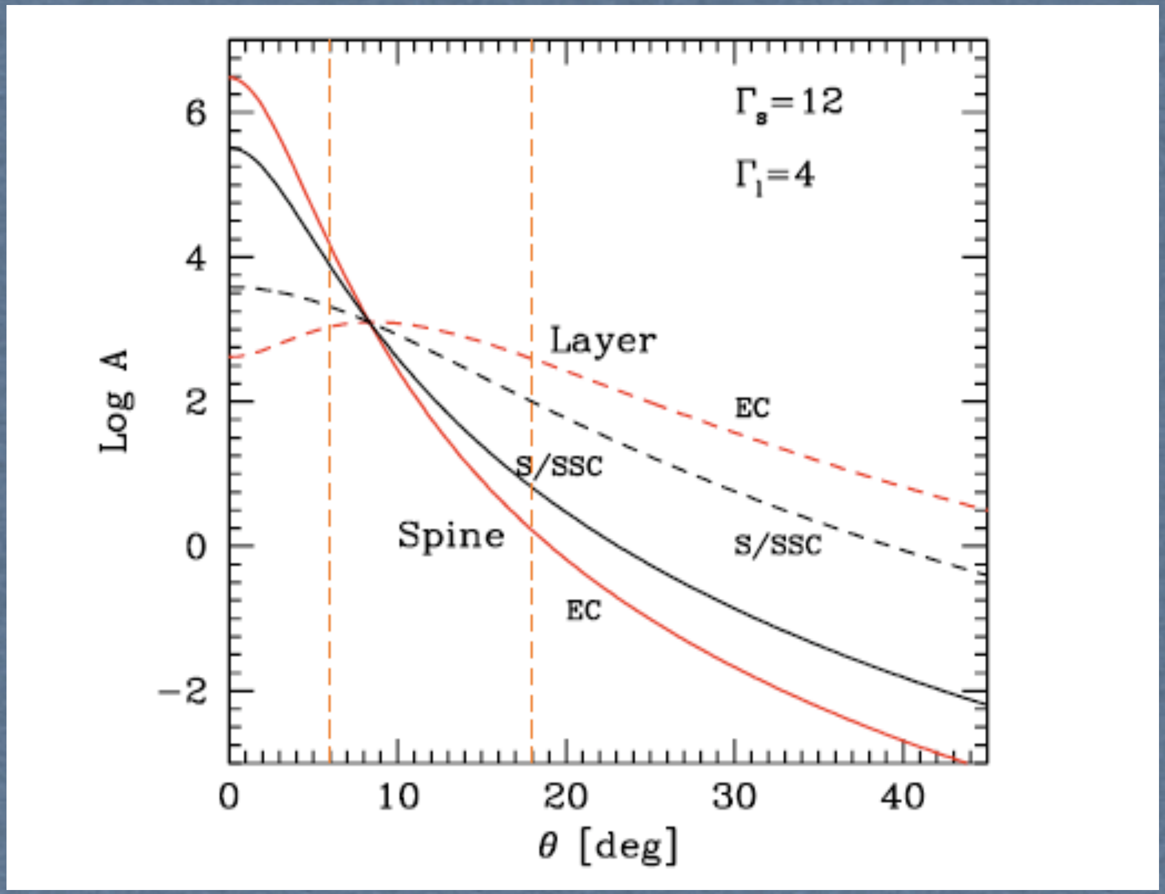
$\Theta = 25°$

$\Gamma_{Layer} = 2.4$

$\Gamma_{Spine} = 15$

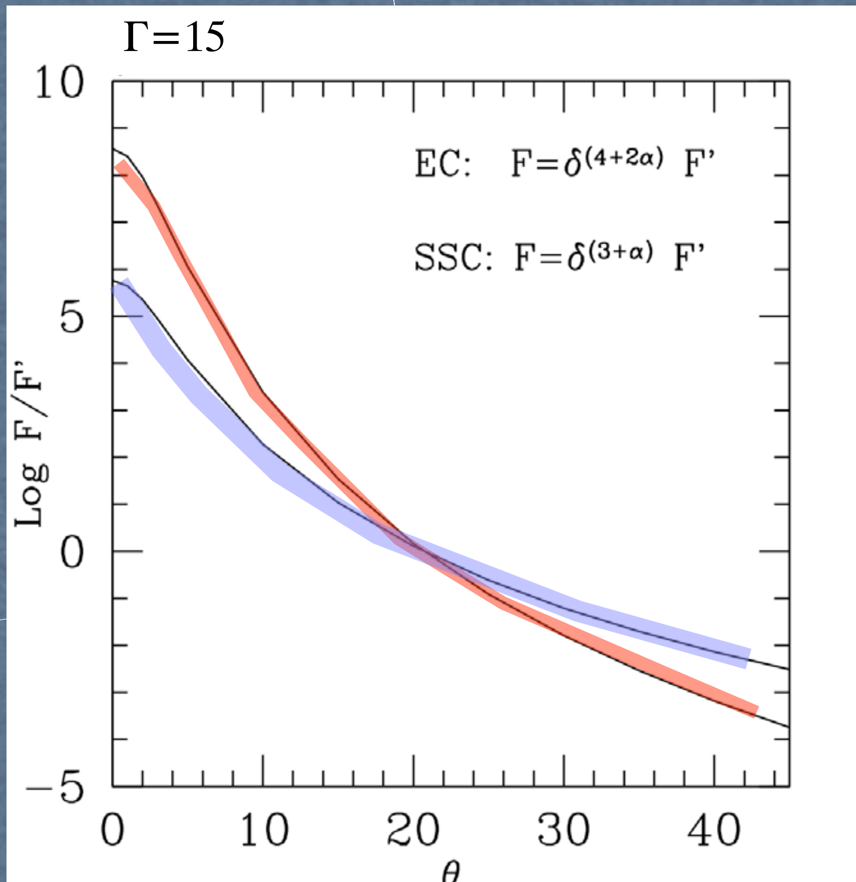
In the spine-layer and decelerating models there is an efficient (radiative) feedback between different regions in the jet that increases the IC emission.

Models can fit the Spectral Energy Distributions of FRIs.



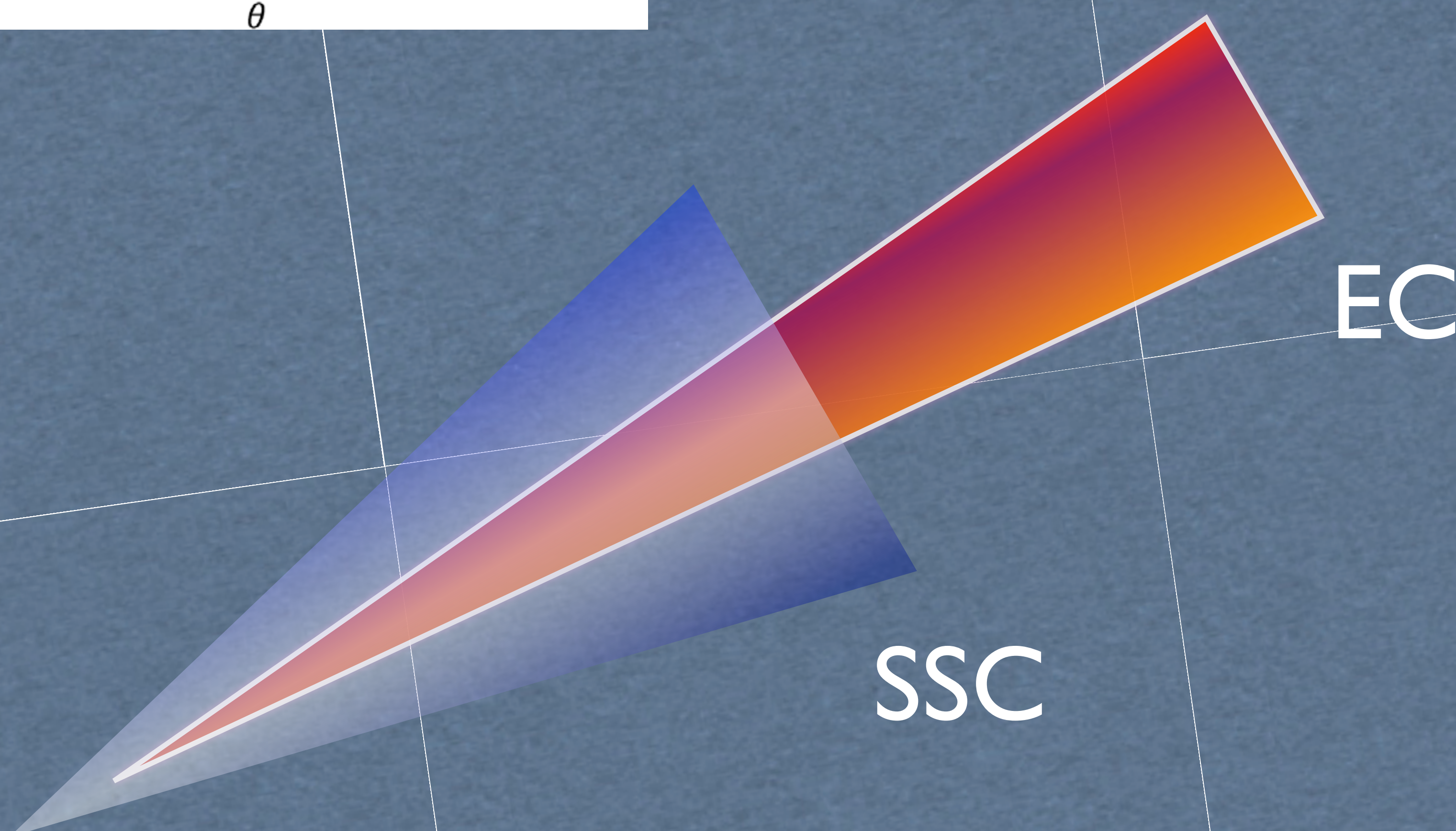

The jet of FRIIs could be less structured (spine dominated) or/and less decelerated

# and/or




In FRII the jet propagates through a photon rich environment (see Torresi's talk) => EC dominant mechanism .

EC emission is narrower in the beaming direction than the SSC radiation (Dermer 1995, ApJ, 446, L63)



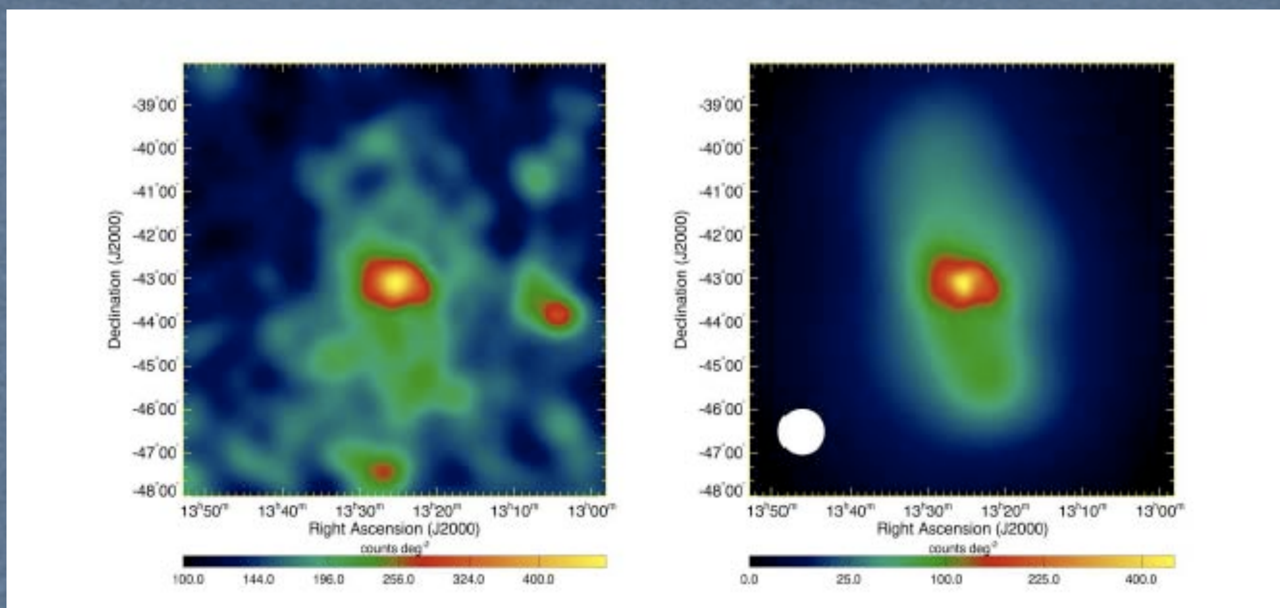
Third question

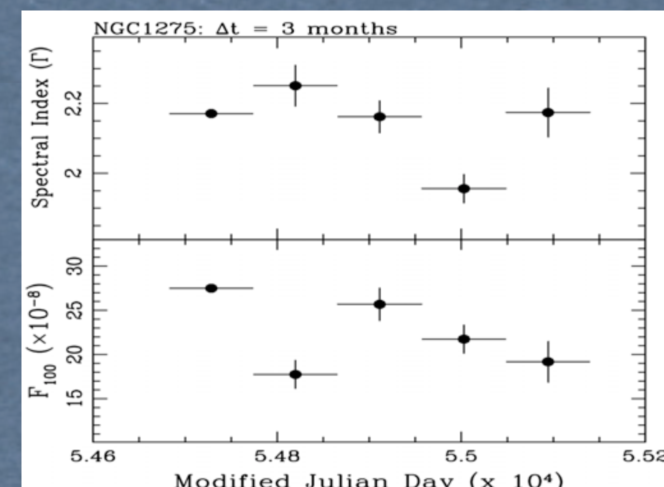
Where do the $\gamma$-rays originate in radio galaxies ?

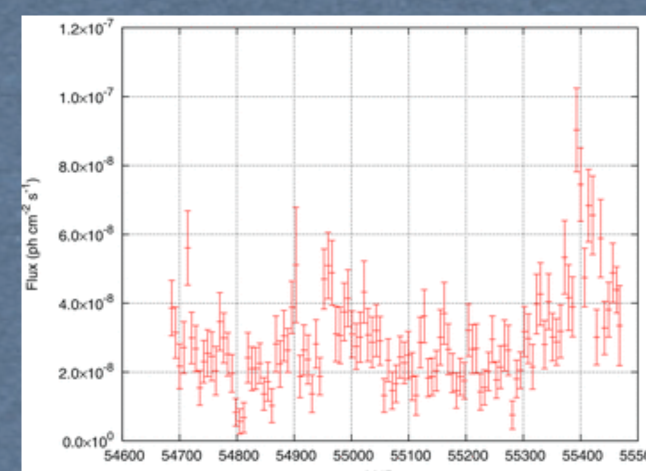
# Where are the $\gamma$-ray produced in Radio Galaxies?

in/near the radio core (sub-pc/pc scales)?

in large extended regions (kpc-scale structures)



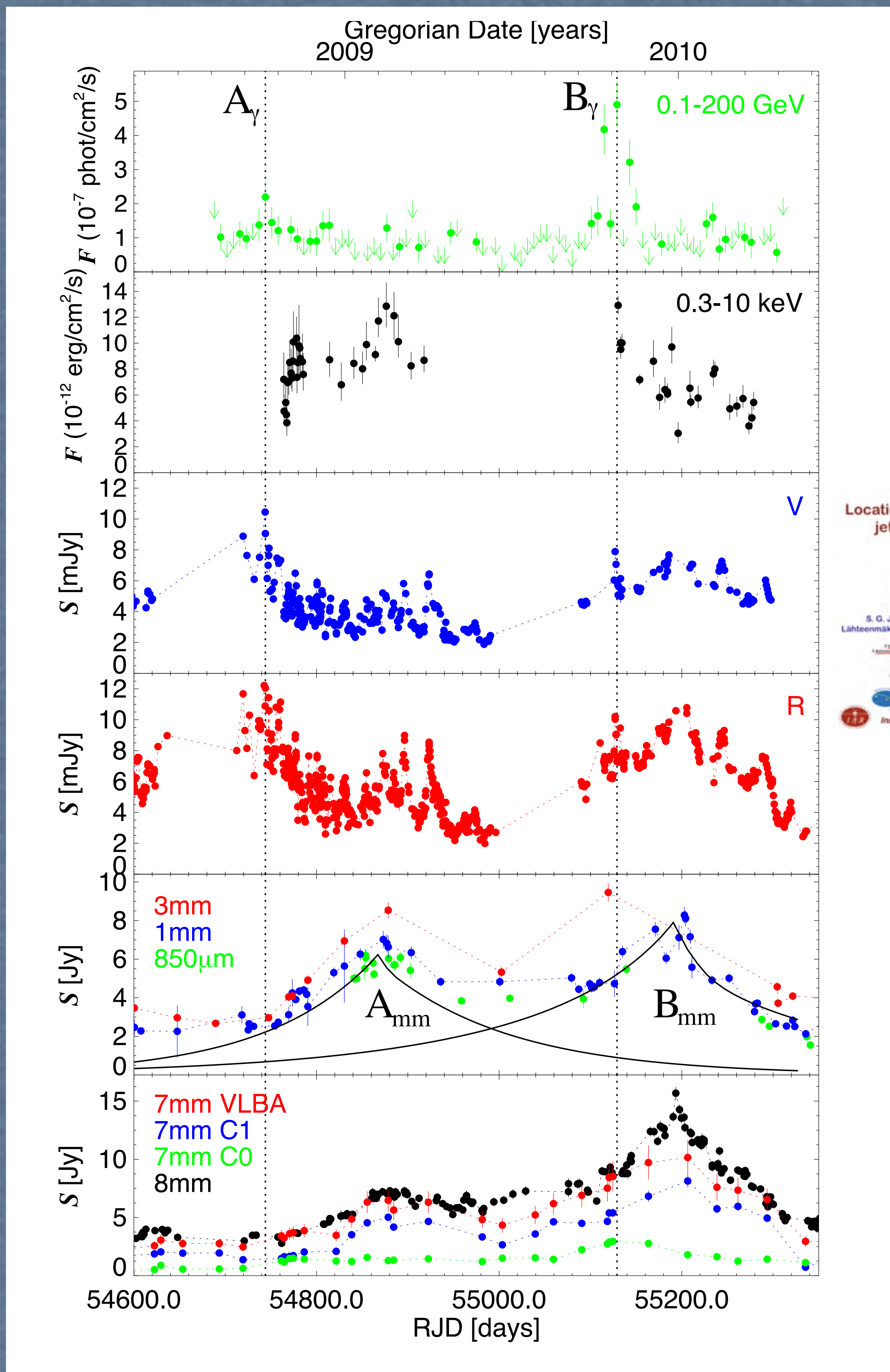



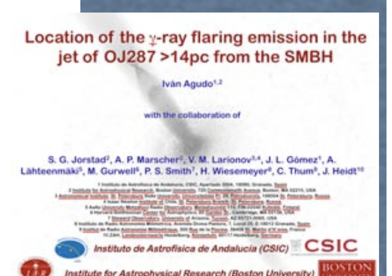

Cen A Lobes
Abdo et al. 2010, Science, 328, 725

NGC1275
Abdo et al. 2010 (MAGN)
Brown&Adams 2011

# Some inspiring Results on BLazars presented at the HEPROIII Meeting in Barcellona last summer

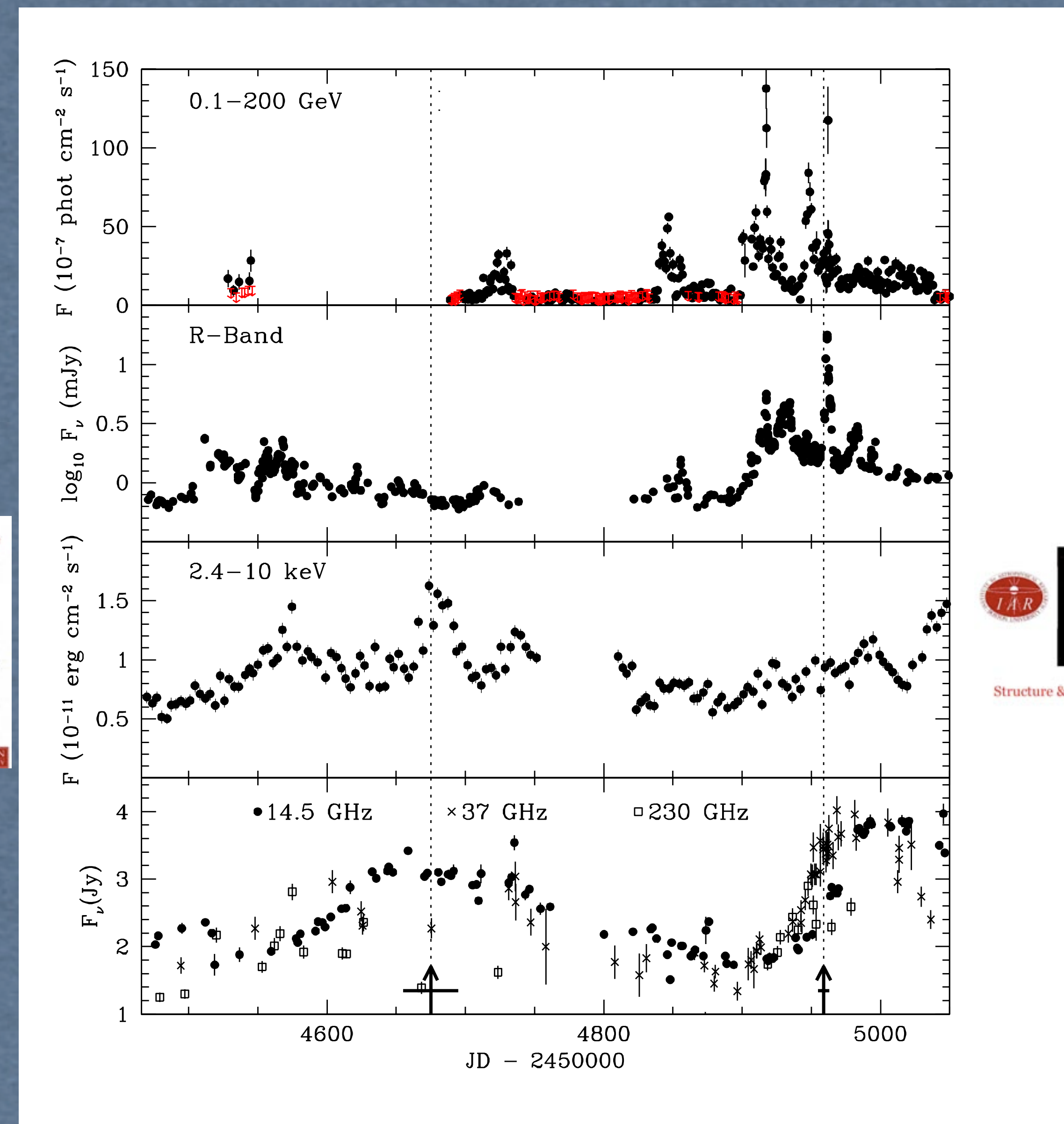
## BL Lac OJ287




Agudo et al. 2011(ApJL 2011)
$\gamma$-ray flare more than 14 pc
from the central engine

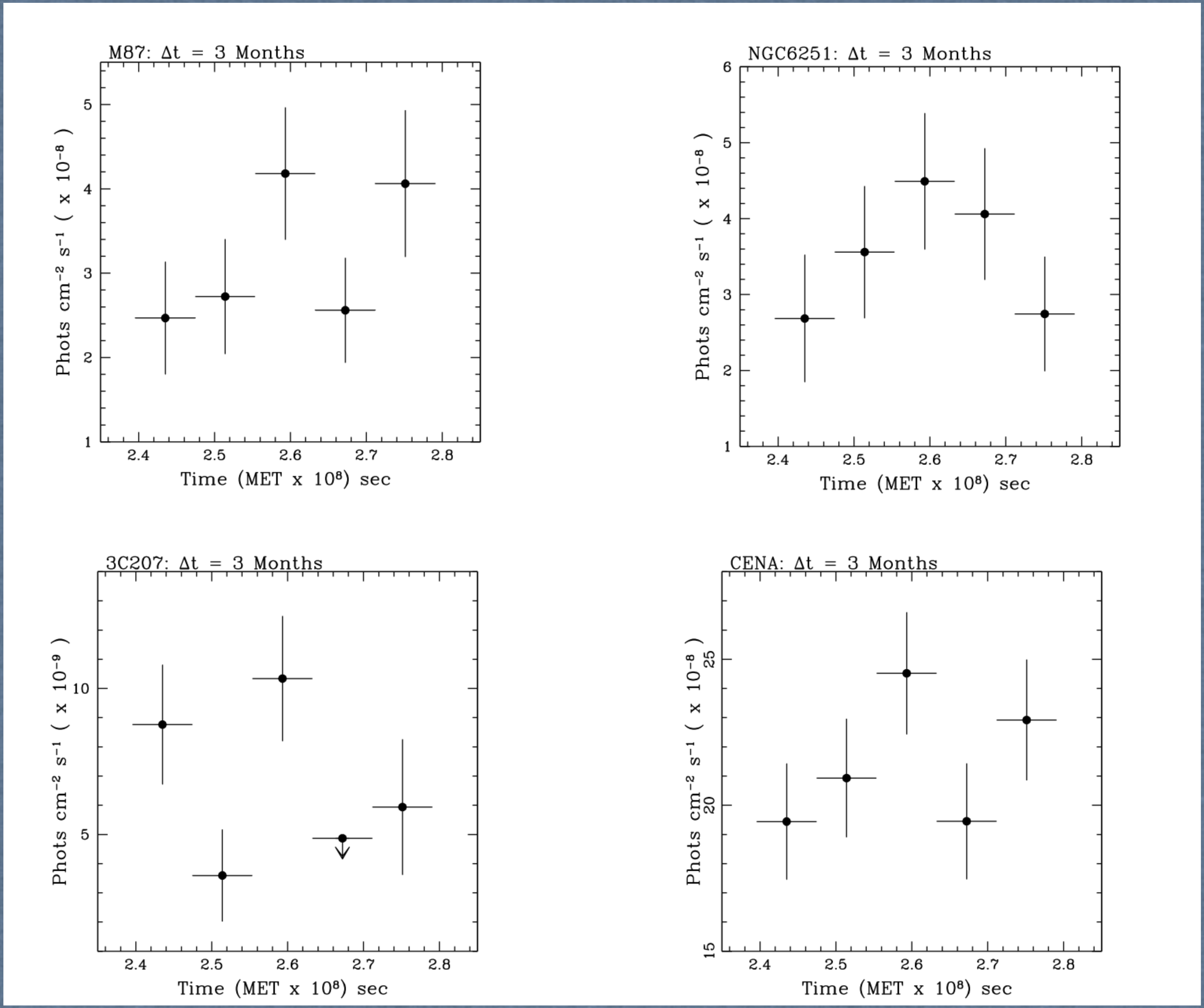
## FSRQ PKS 1510-089



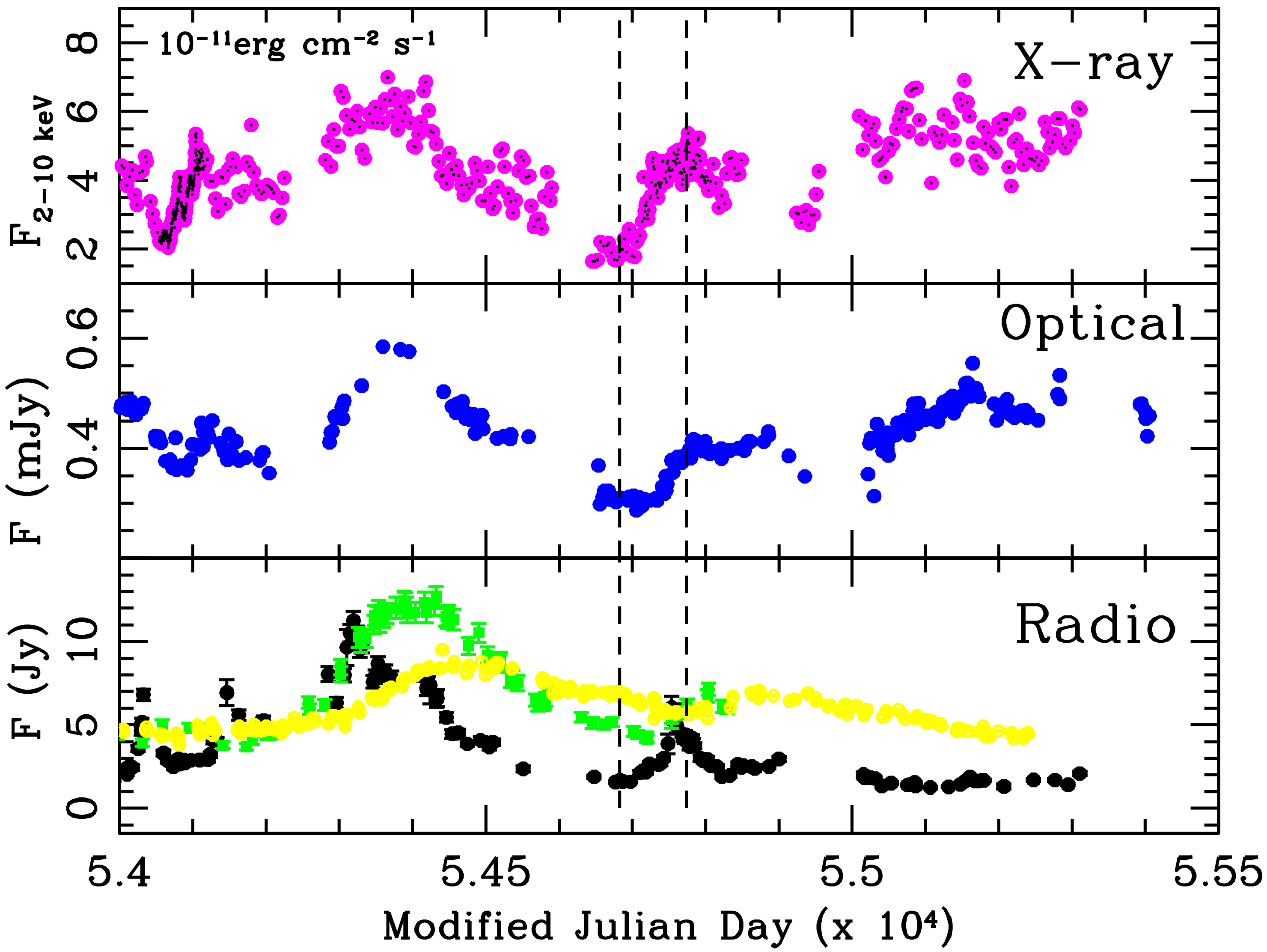


Marscher et al. 2010 (ApJL 2010)
complex $\gamma$-ray emission
different/regions-mechanisms as a single disturbance
propagates along the jet

# In general it is difficult to detect $\gamma$-ray variability in MAGNs (Abdo et al. 2010 MAGN)



# 3C111 FRII BLRG
# $\gamma$-ray coming from the radio core




x-ray, optical radio data from Chatterjee et al. 2011
http://www.bu.edu/blazars/VLBA_GLAST/3c111.html

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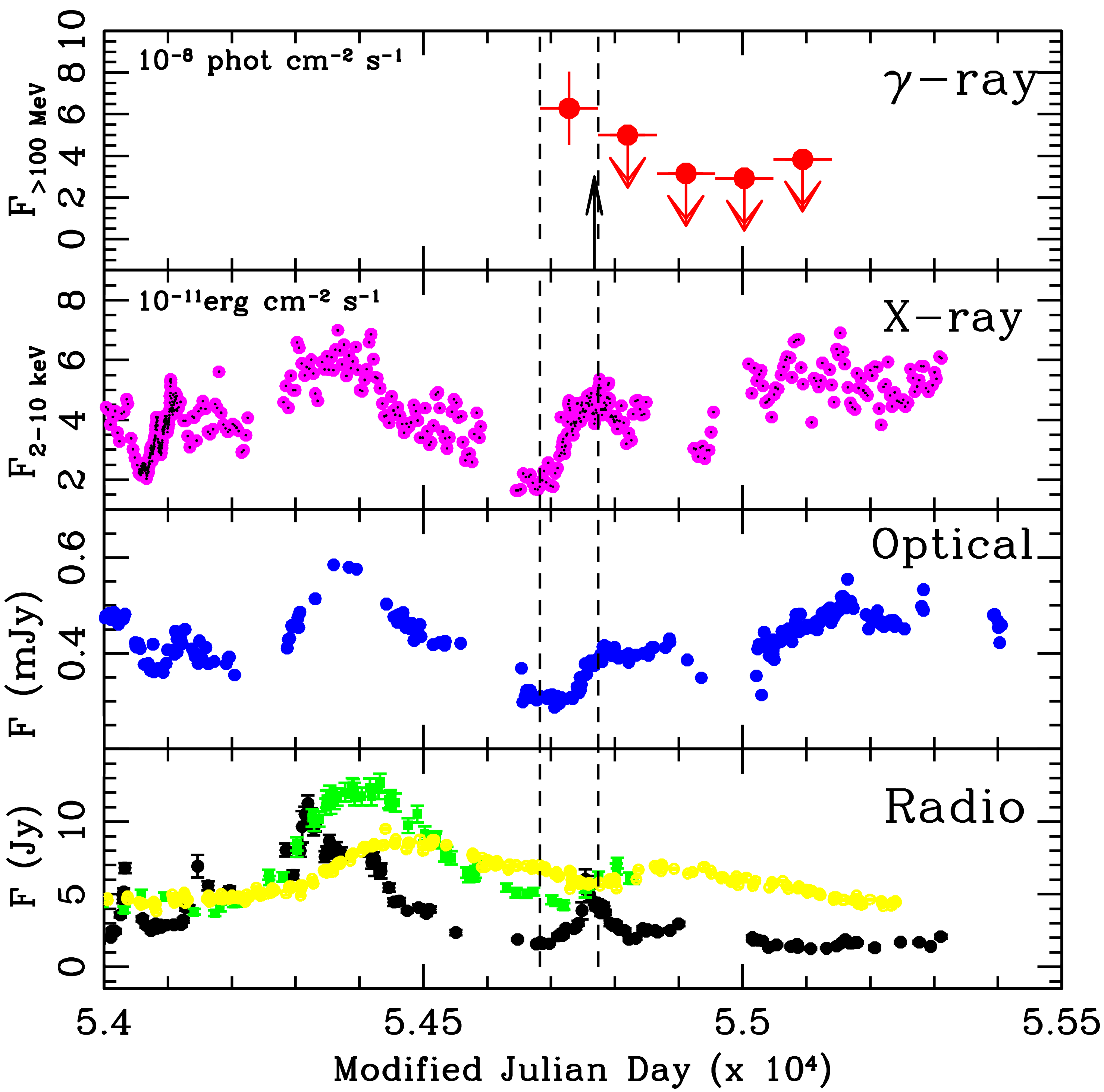
# $\gamma$-ray coming from the radio core

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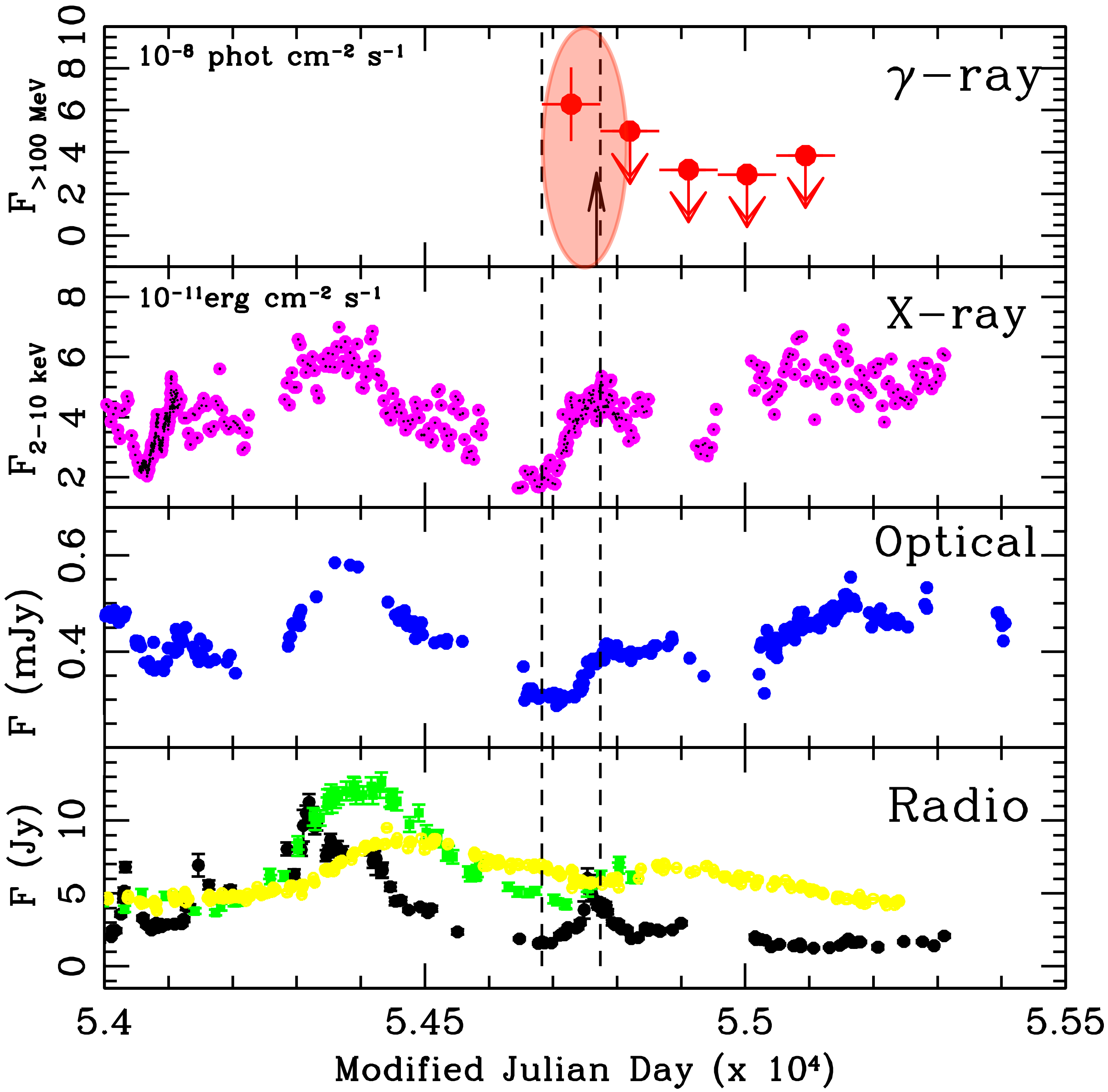


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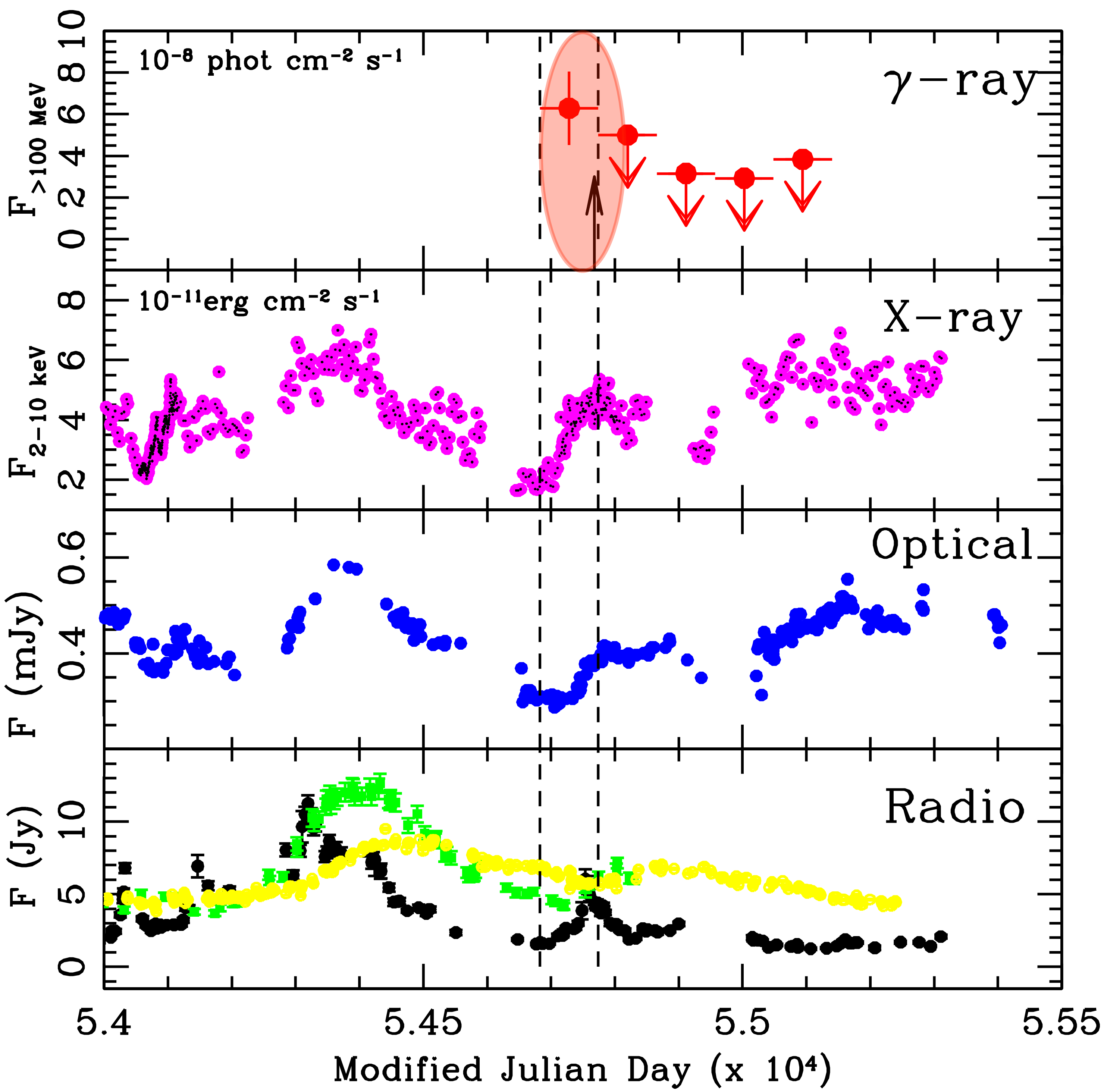


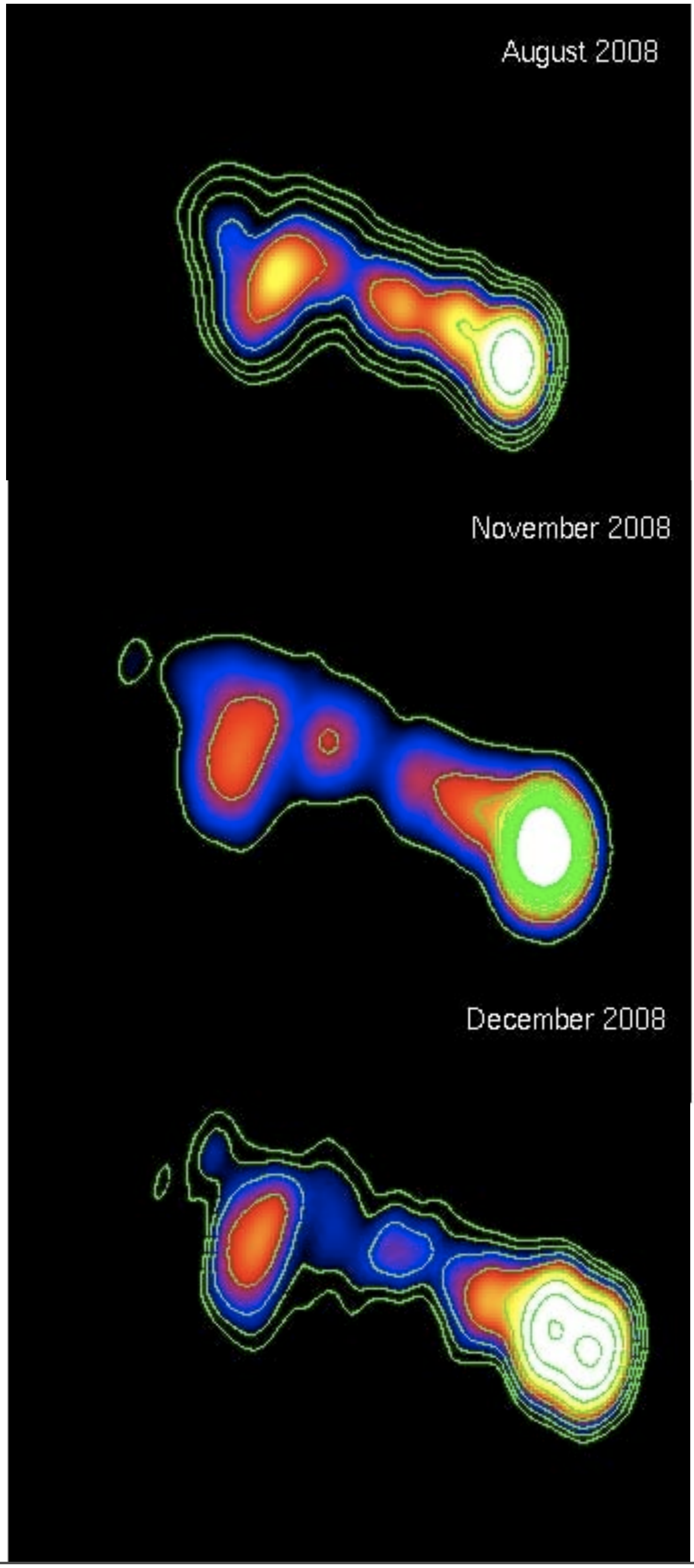


x-ray, optical radio data from Chatterjee et al. 2011
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# Conclusions

97% of the Fermi sources are BL LACs and FSRQs.
3% are other kind of objects: NLSy1, SB and MAGNs.

The MAGN class is mainly populated by FRI radio galaxies. The presence of inhomogeneous jets in these sources seems to favor their detection.

**Paucity of FRIIs**

FRIIs are difficult to detect in gamma. The study of all the gamma-counterparts of 4 complete radio catalogs weakens the hypothesis that the FRIIs are missed because too far.

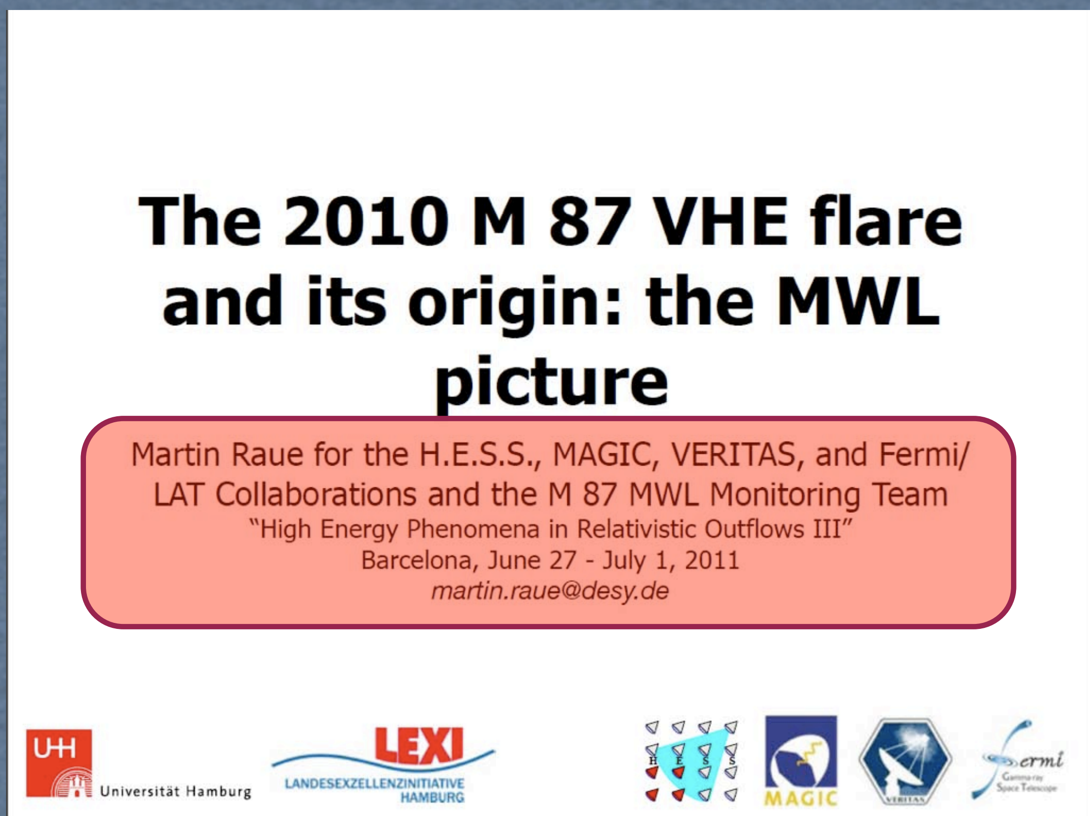
Two effects could be contribute to reduce the number of FRIIs observed by Fermi:
i) the absence/reduction of feedback between different jet layers (particularly efficient mechanism in FRI with large inclination angles) ;
ii) the $\gamma$-ray narrower beaming cone of External Compton scattering (EC) when compared to that of the synchrotron-self processes (SSC).

**$\gamma$-ray origin in MAGns**

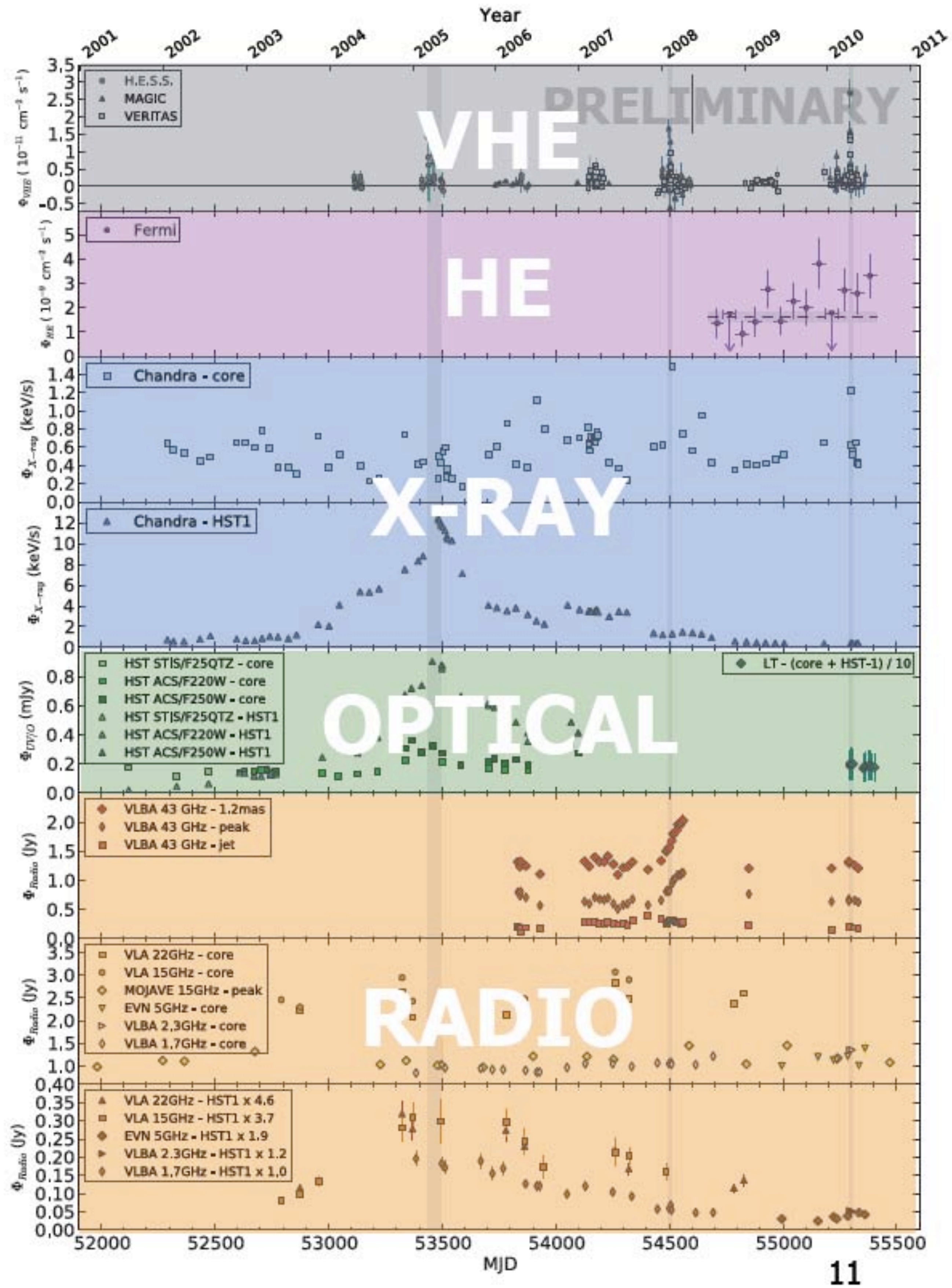
It is attested that both extended (kpc scales) and compact (sub-pc/pc scales) regions can emit high-energy photons in FRIs. No spatial identification of $\gamma$-ray source in FRIIs has been provided up to now.

A multiwavelength study comparing X-ray, optical, radio (Chattarjee et al 2011) and Fermi-LAT data (Abdo et al. 2010) allows to localize for the first time the $\gamma$-ray region in a FRII radio galaxy.
In 3C111 the base of the jet (core) is the probable site (BLR) of MeV-GeV photon production.

M87: first attempts to localize high energy emission-region in a MAGN
Raue et al.



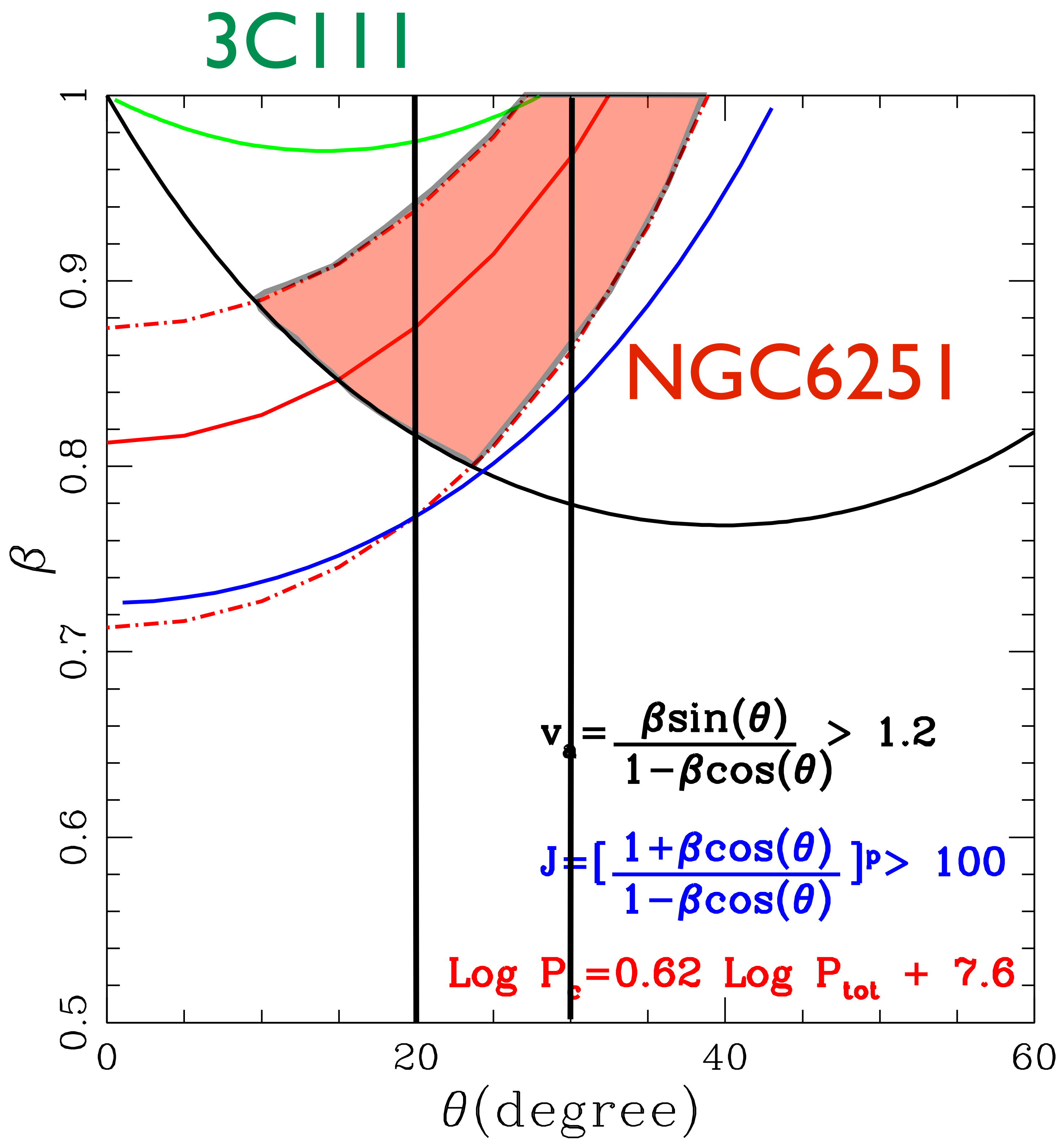

Hepro III-meeting




## Origin of the VHE emission?

No unique solution?

2005: HST-1? 2008: Core? 2010: ? .. but **X-ray core (2008/10)**


3C111
NGC6251
$v_a = \frac{\beta \sin(\theta)}{1-\beta\cos(\theta)} > 1.2$
$J = [\frac{1+\beta\cos(\theta)}{1-\beta\cos(\theta)}]^p > 100$
Log $P_c$=0.62 Log $P_{tot}$ + 7.6
β
0.5
0.6
0.7
0.8
0.9
1
0
20
40
60
θ(degree)