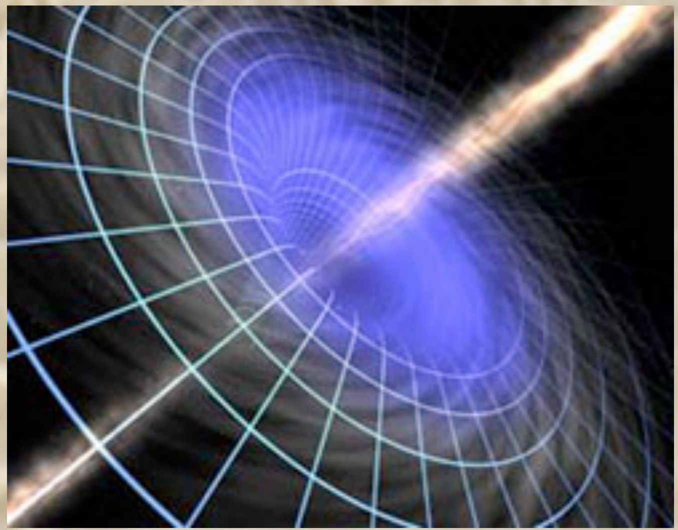
Gamma-Ray Variability Study of Misaligned AGN



Paola Grandi, Eleonora Torresi

A. De Rosa, S. Raino, P. Malaguti

on behalf of the Fermi LAT Collaboration

The Innermost Regions of Relativistic Jets
and their Magnetic Field
Granada, Spain, June 10-14 2013

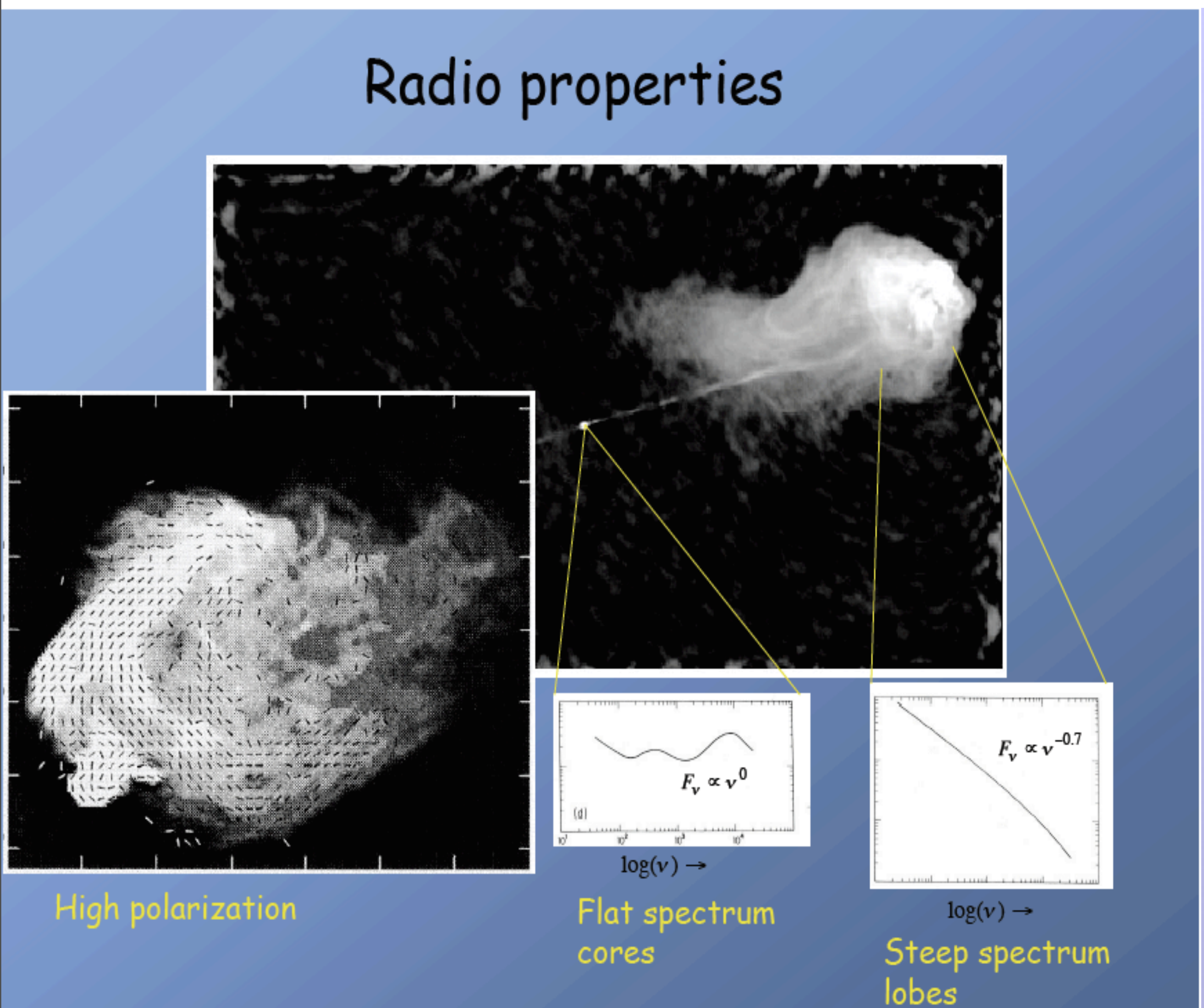
MAGNs show:

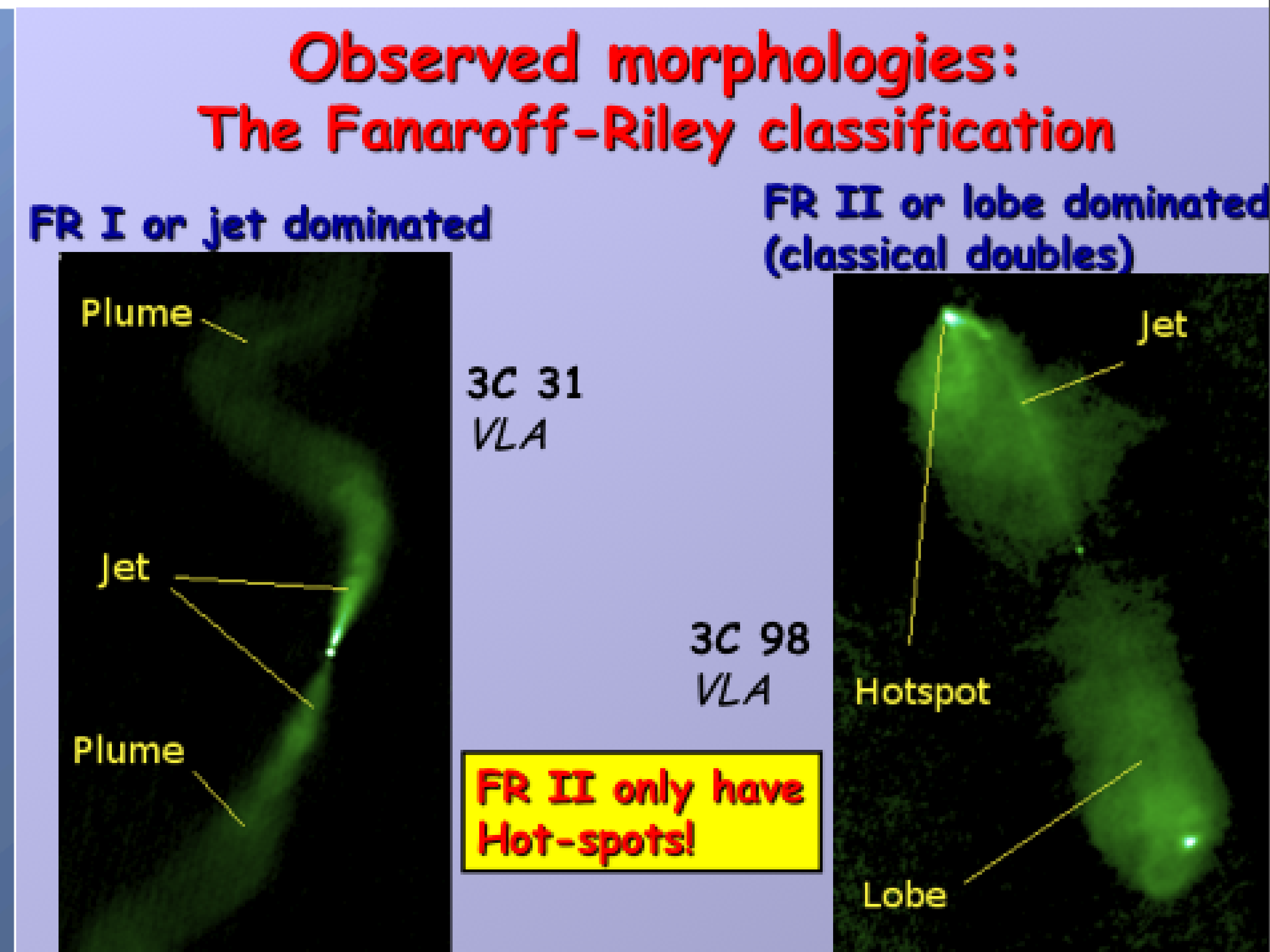
Steep radio spectra

$\alpha_r > 0.5$

and/or

Resolved and possibly symmetrical structure in radio map





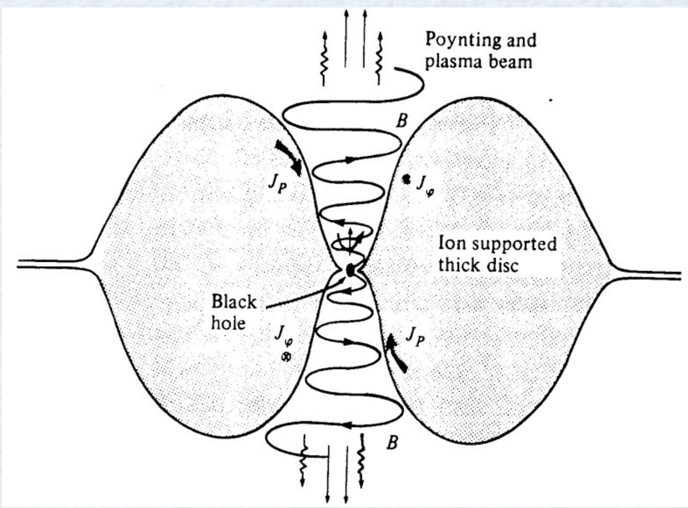
FRI are considered the PARENT POPULATION of BL LACs

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

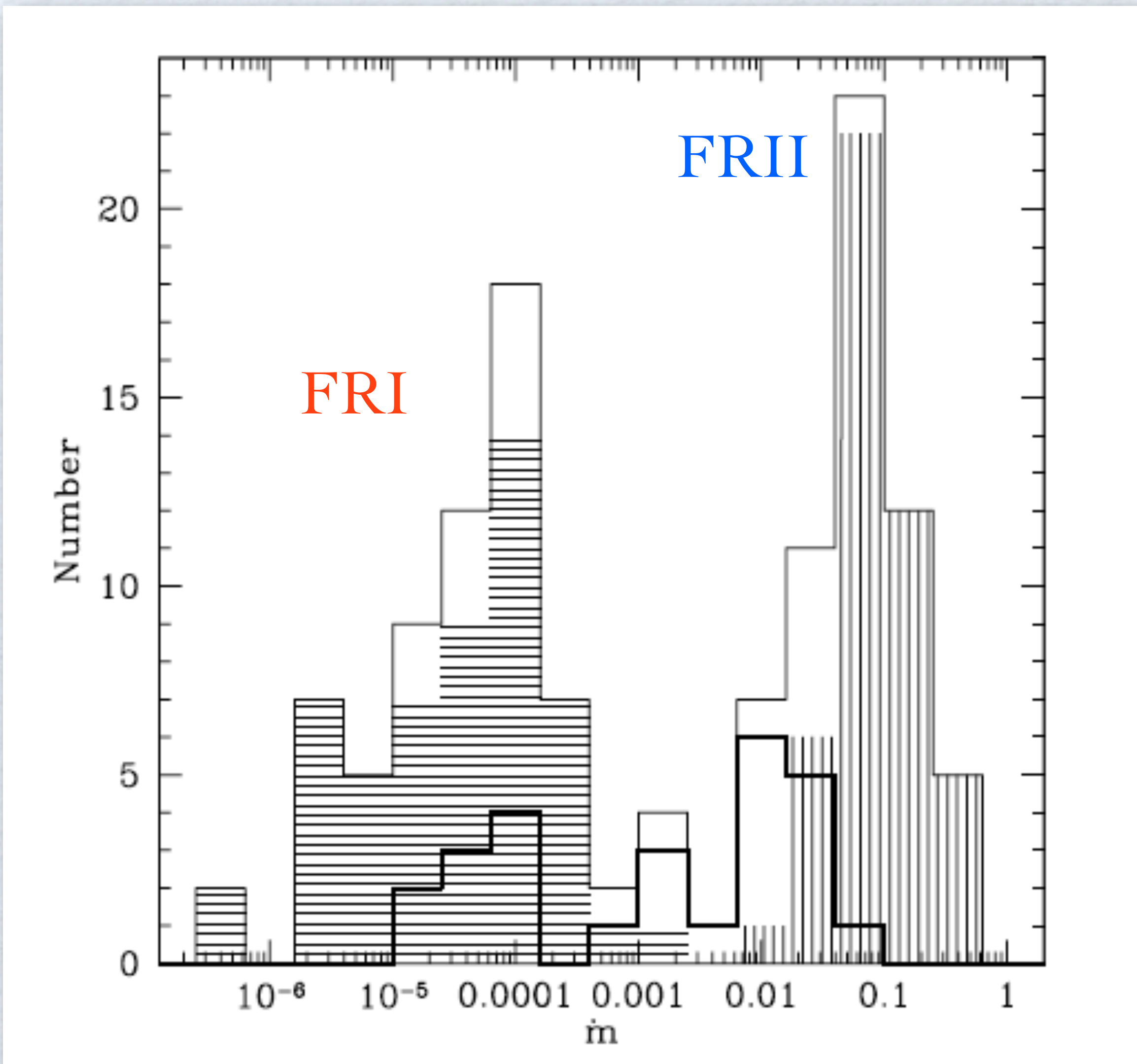
The Accretion/ejection system could be different in powerful AGN with different radio morphologies

The accretion rate distribution is bimodal:

Low accretion rates => FRI



The accretion flow is hot and thick



Marchesini, Celotti, Ferrarese 2004

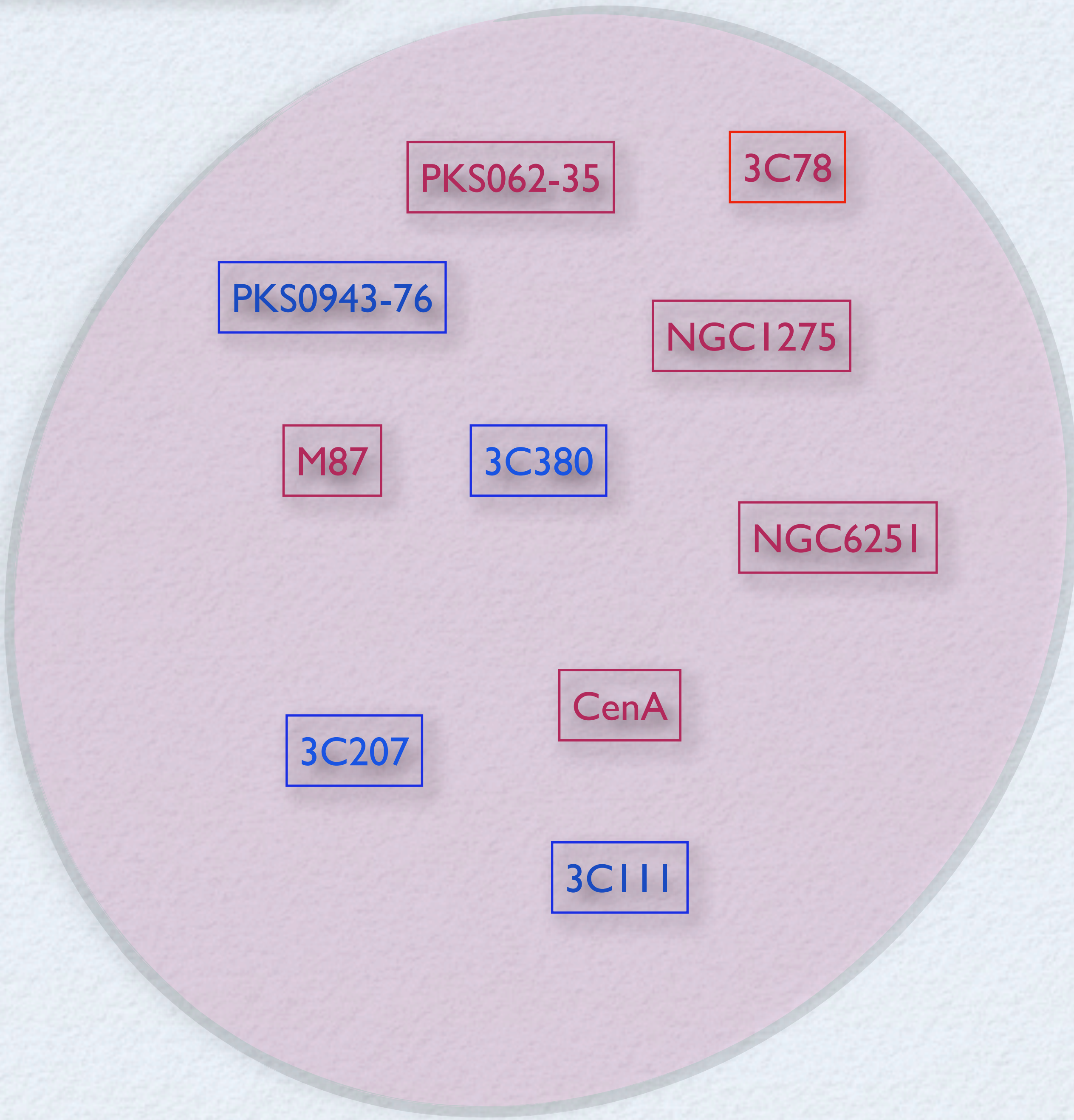
High accretion rate => FRII

(H<<R)

The disk is cold and thin

MAGN in the GeV sky

The First Catalog
of AGN (1LAC) contains 10 MAGN



FRI
FRII

MAGN in the GeV sky

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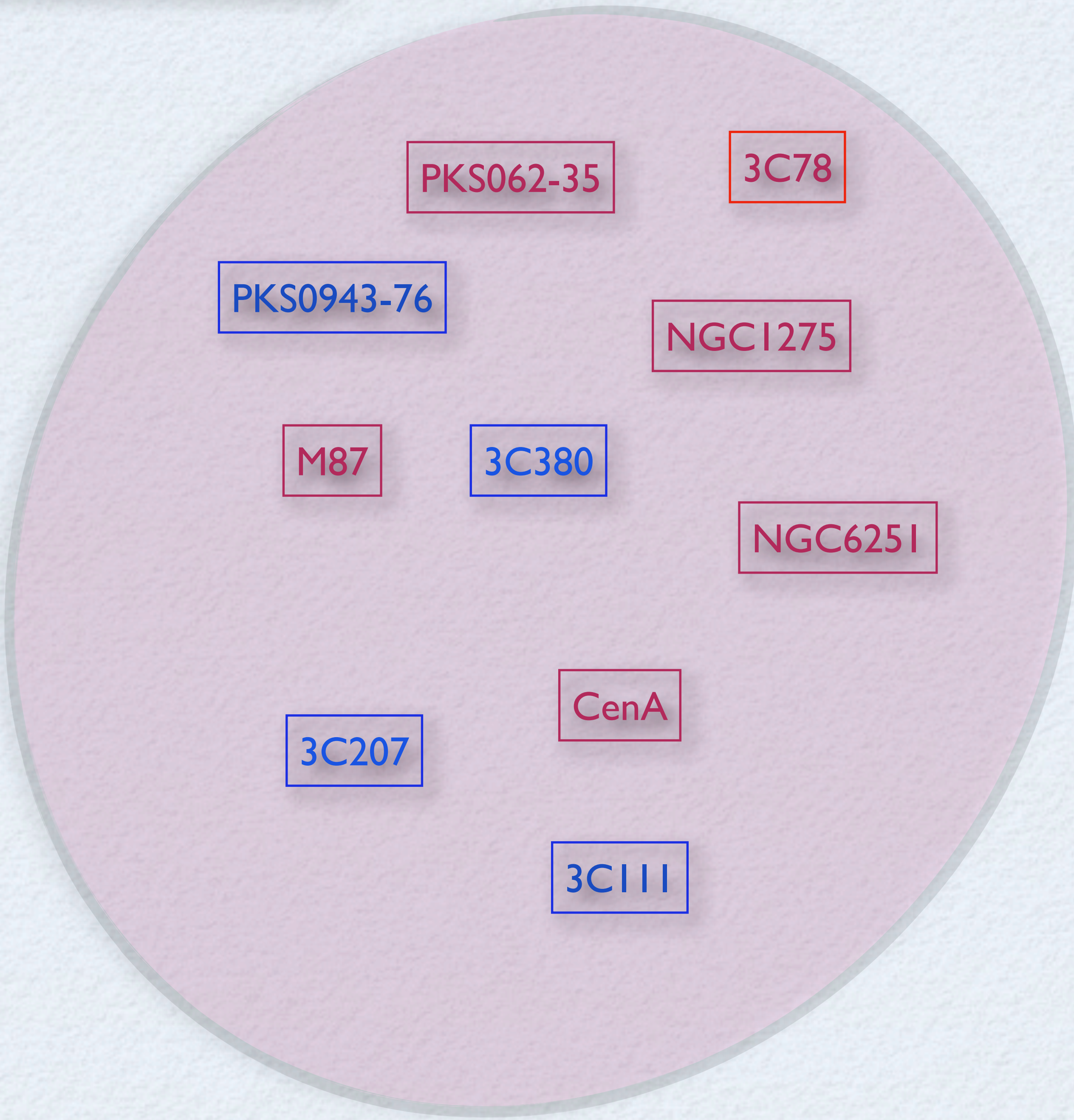


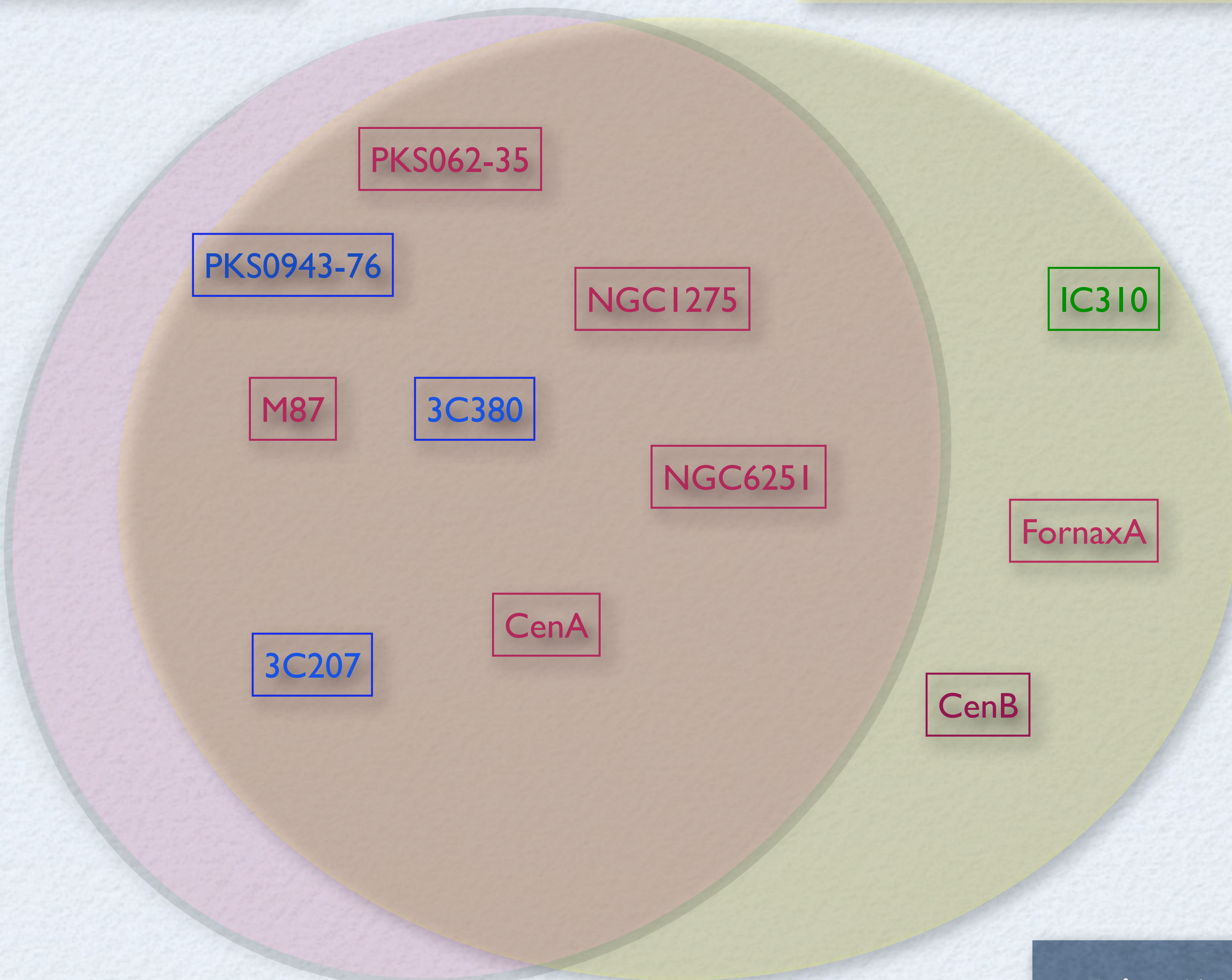
FRI
FRII

The MAGN 15-month
sample includes 3C 120

MAGN in the GeV sky

The First Catalog of AGN (1LAC) contains 10 MAGN

In the Second Catalog of AGN (2LAC), the number of detected MAGNs is 11



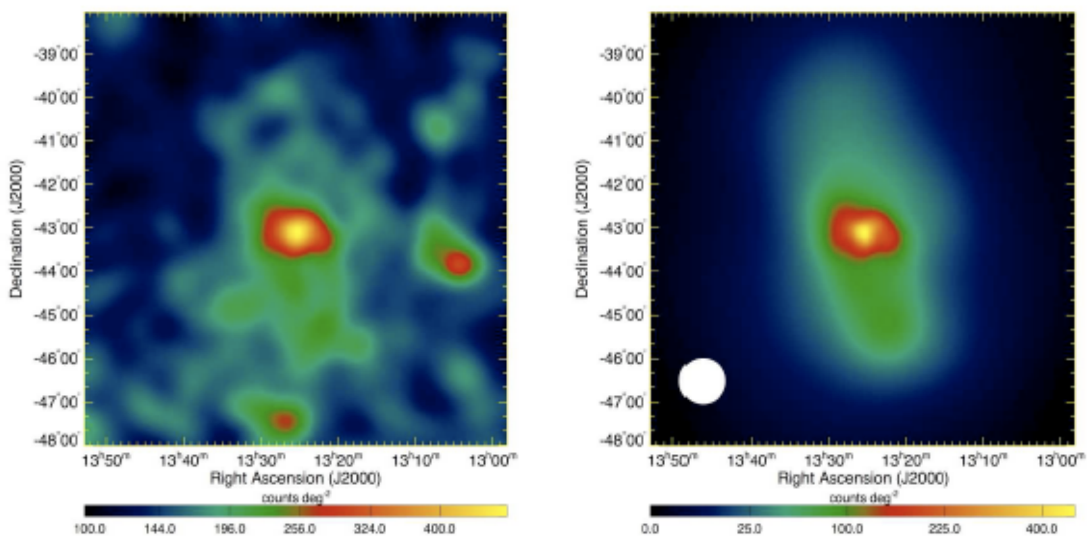
Kadler et al. 2012, A&A, 538, L1

FRI
FRII

The MAGN 15-month sample includes 3C 120

Where are γ-rays produced in Radio Galaxies?

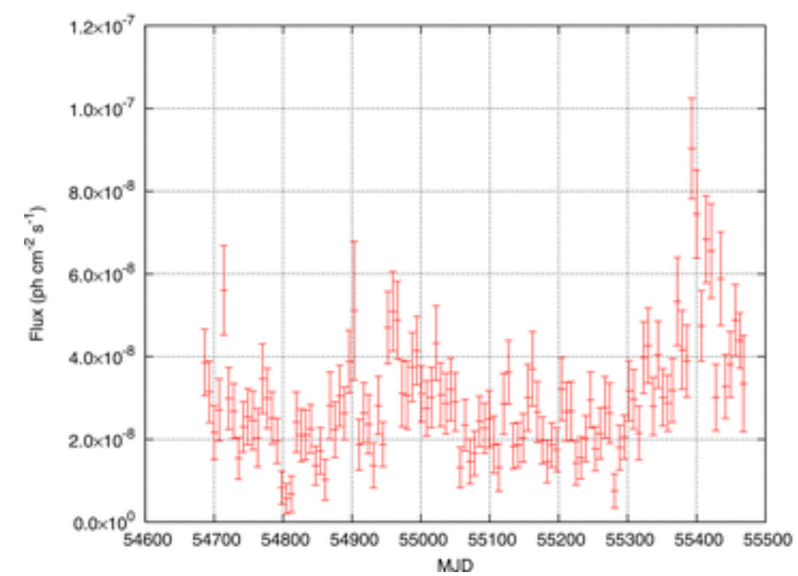
in large extended regions (kpc-scale structures)



Cen A Lobes

Abdo et al. 2010

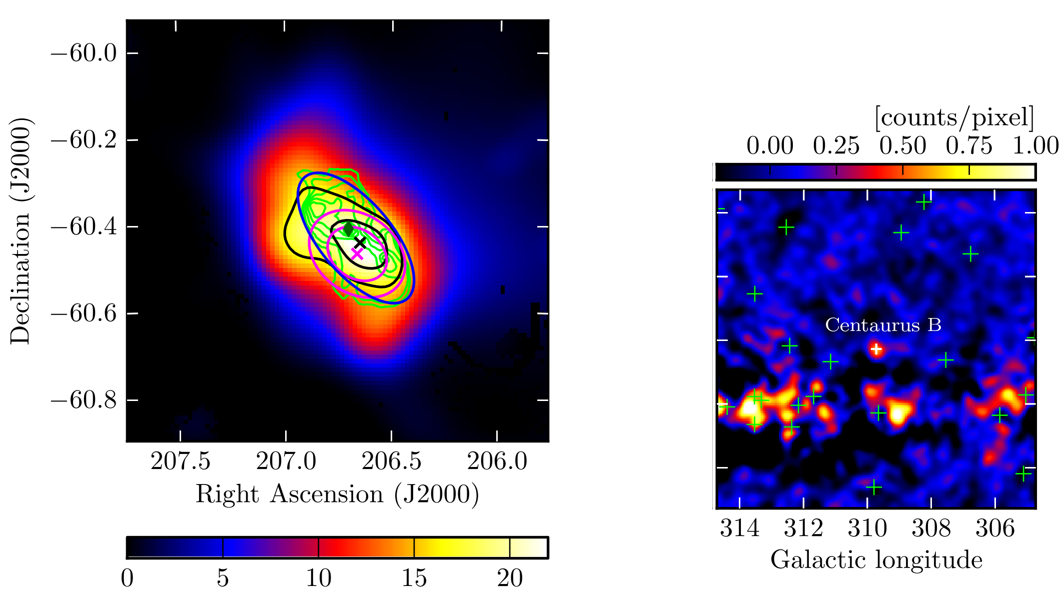
in/near the radio core (sub-pc/pc scales)?



NGC1275

Abdo et al. 2010 (MAGN)

Brown&Adams 2011



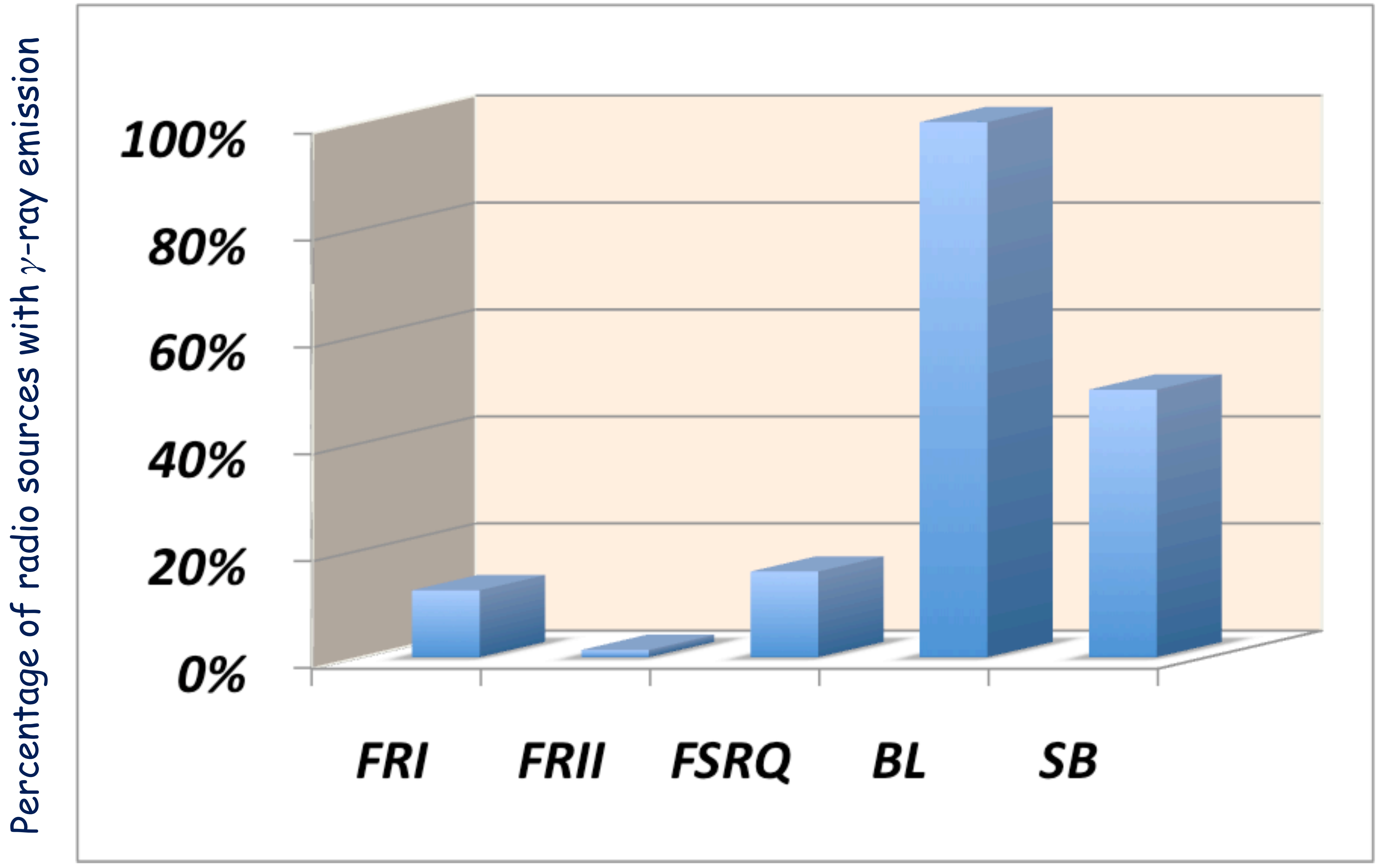
Cen B Lobes possible hint of gamma-ray extension

Katsuta et al. 2012

Detection Rate

Source with TS >25

15 and 24 months of sky survey



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

FRIIs are the less detected objects

The core of FRIIs should be bright enough to be visible at very high energies

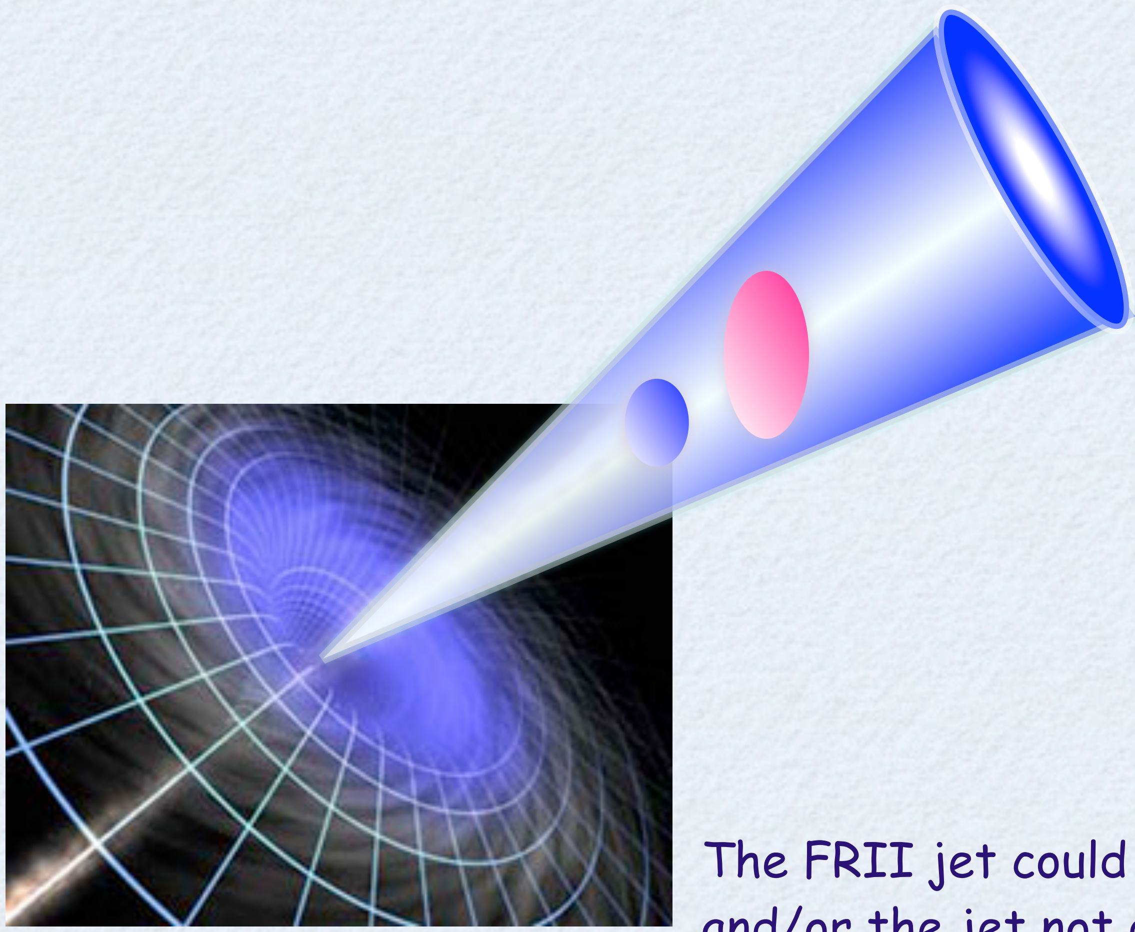
Why does Fermi-LAT preferentially catch FRIs and lose FRIIs ?

Two possible effects have been suggested

The jet could be structured in FRI

Possible solutions to the problems (not the only ones)

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

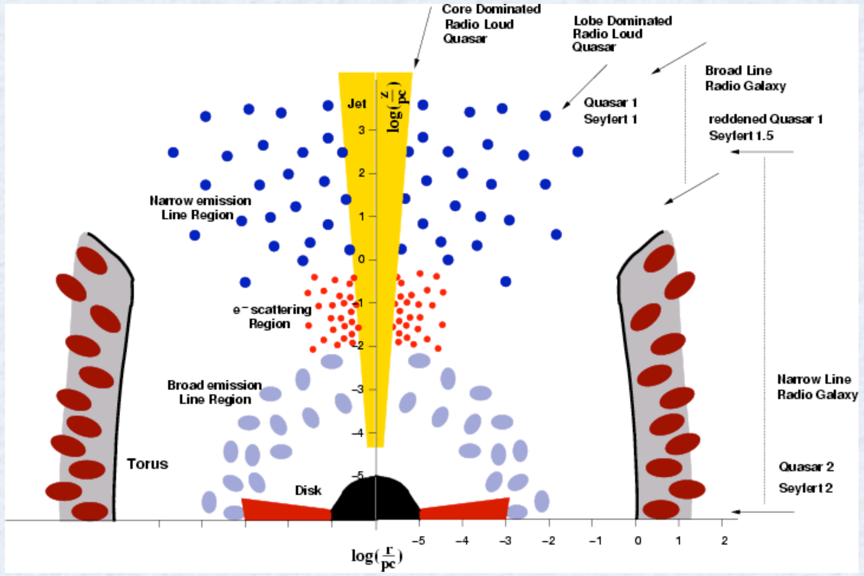


The hypothesis of homogeneity is relaxed and more regions at different velocities are assumed.

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

The FRII jet could be not structured. The external layers could be less prominent and/or the jet not decelerated

The environment could also play an important role

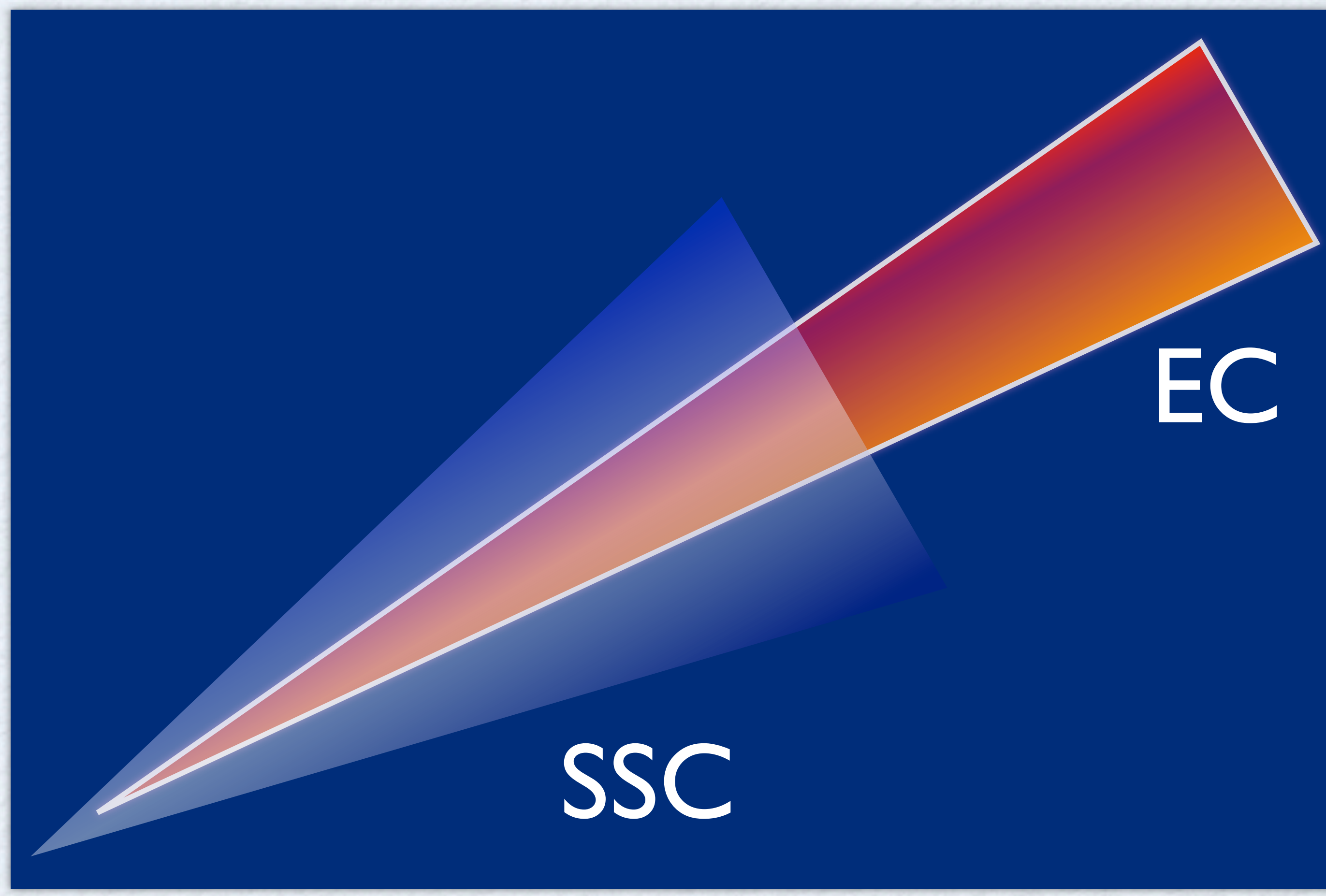


In FRII the jet propagates through a photon rich environment

↓

EC dominant mechanism

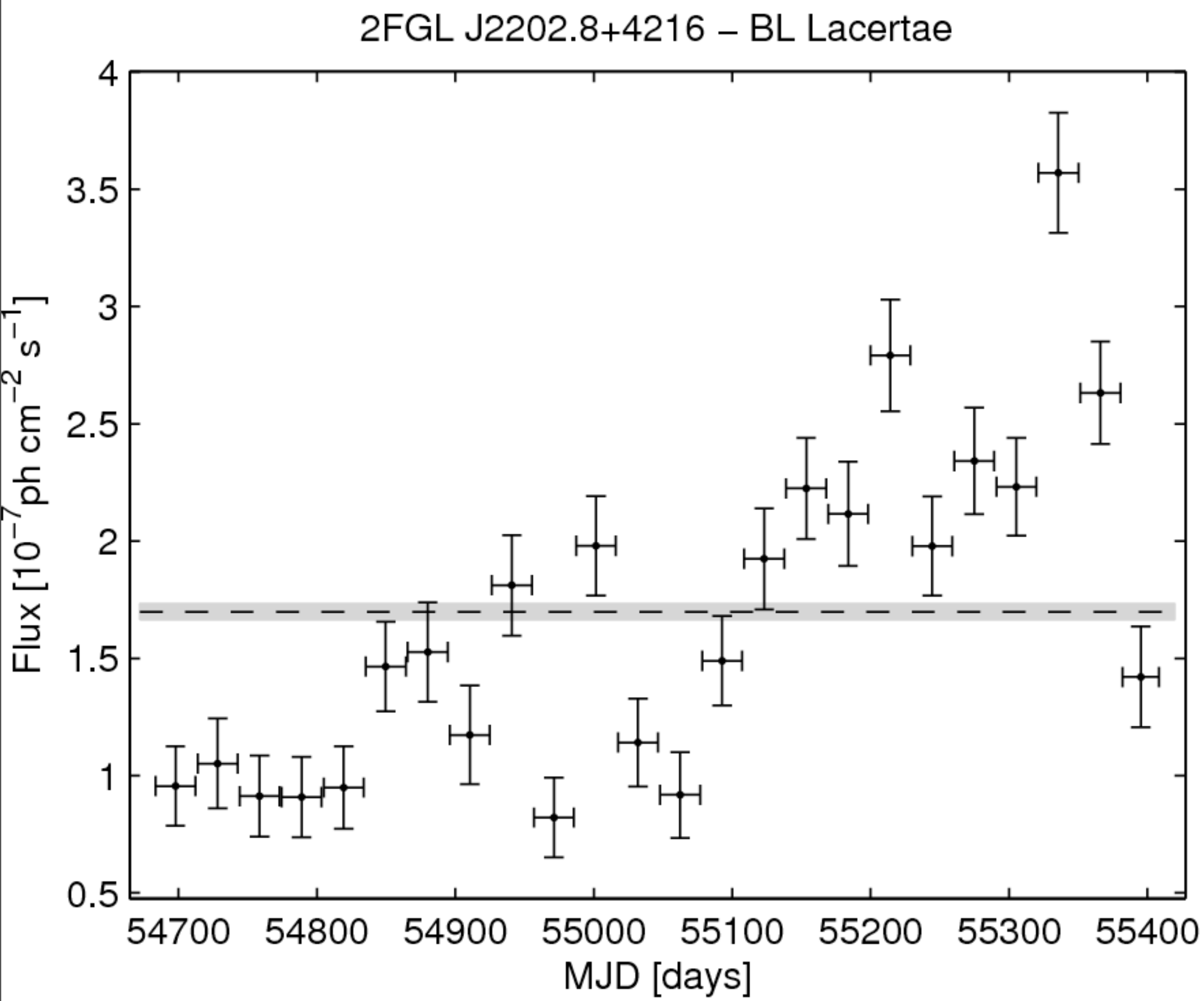
EC emission is narrower in the beaming direction than the SSC radiation (Dermer 1995)

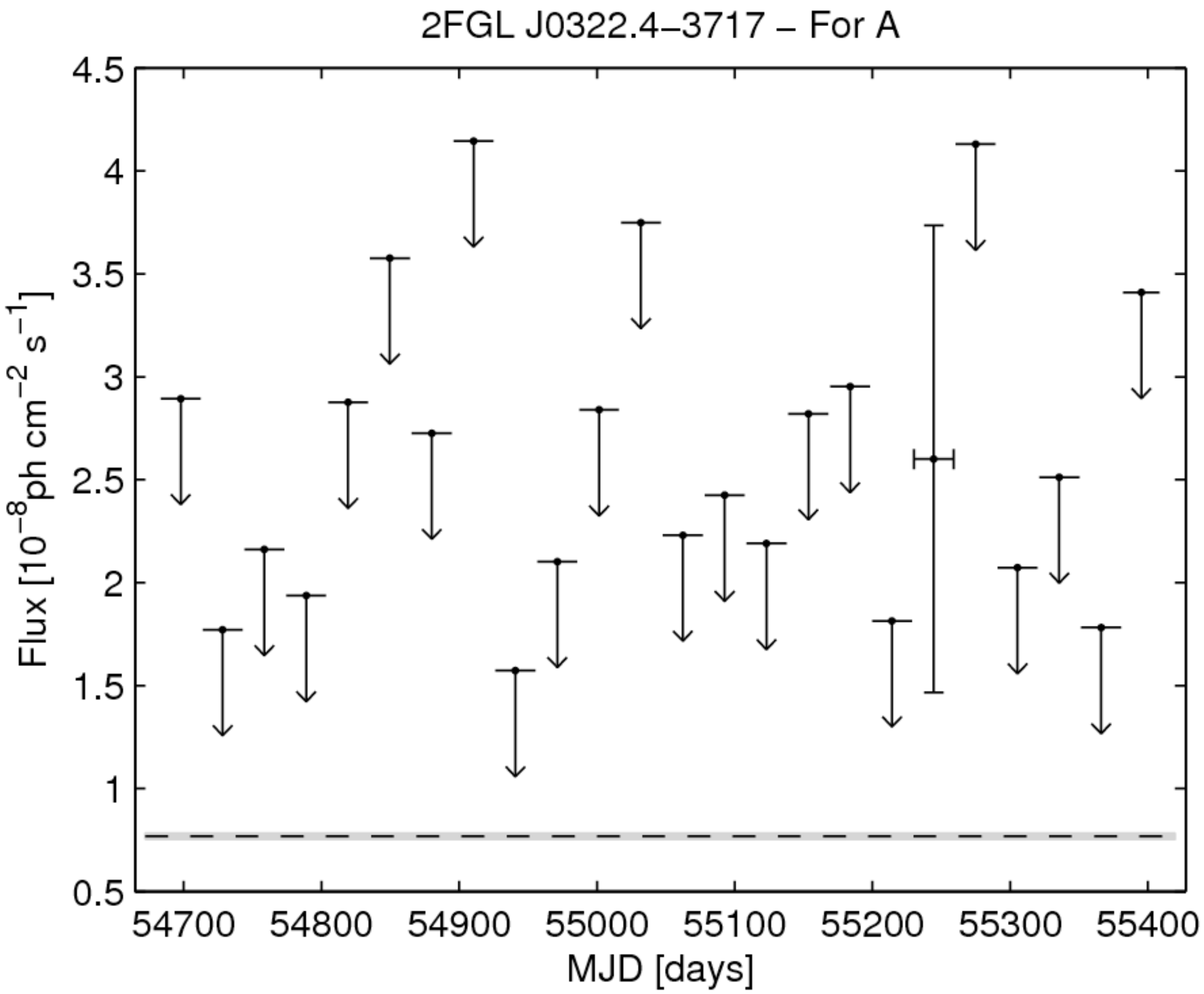


In FRIIs the high energy emission cone could be narrower.

In order to address these still open questions we started a GeV variability study of MAGN

MAGN variability study is sometime frustrating .....

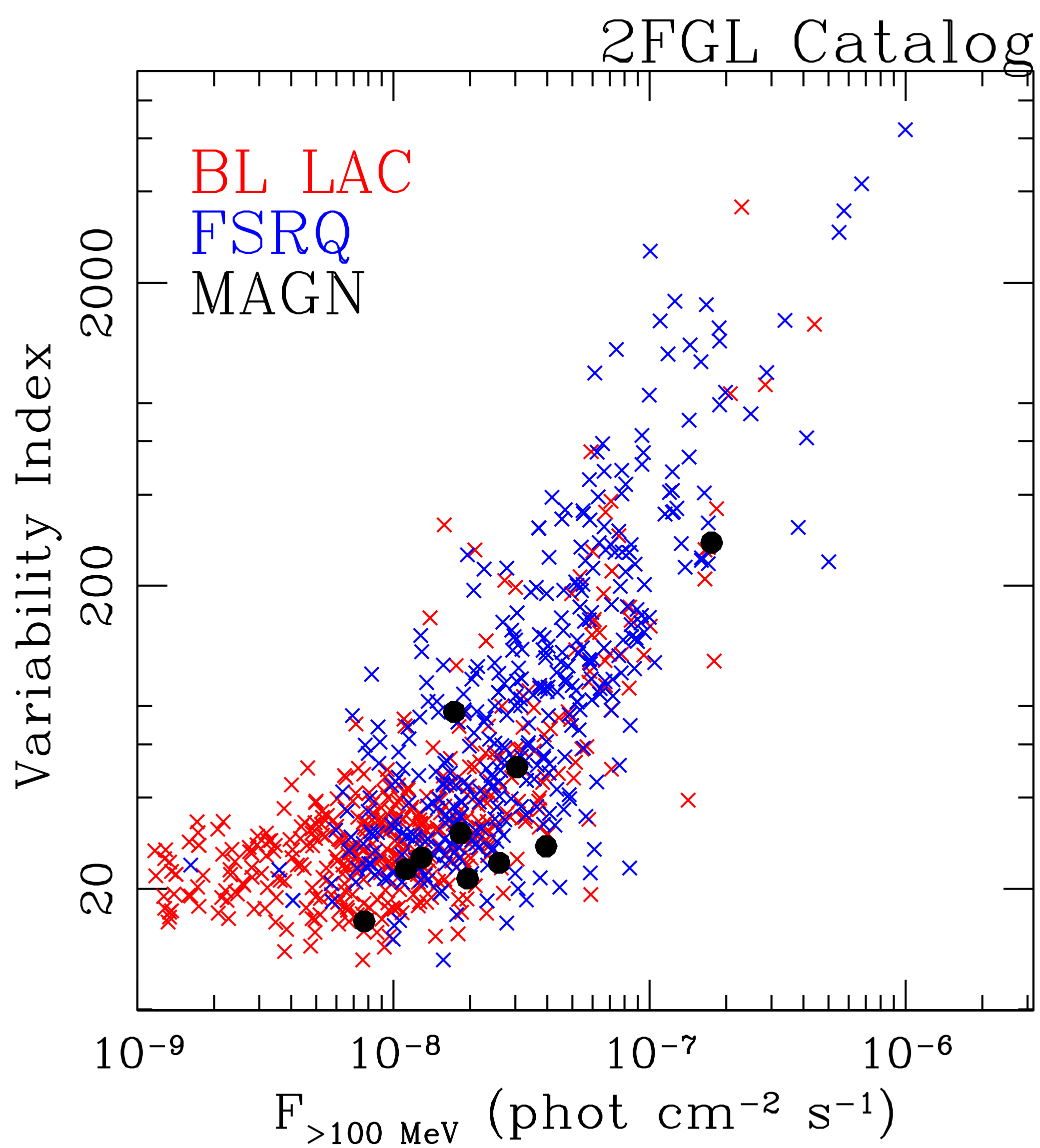




BLAZAR

Radio Galaxy

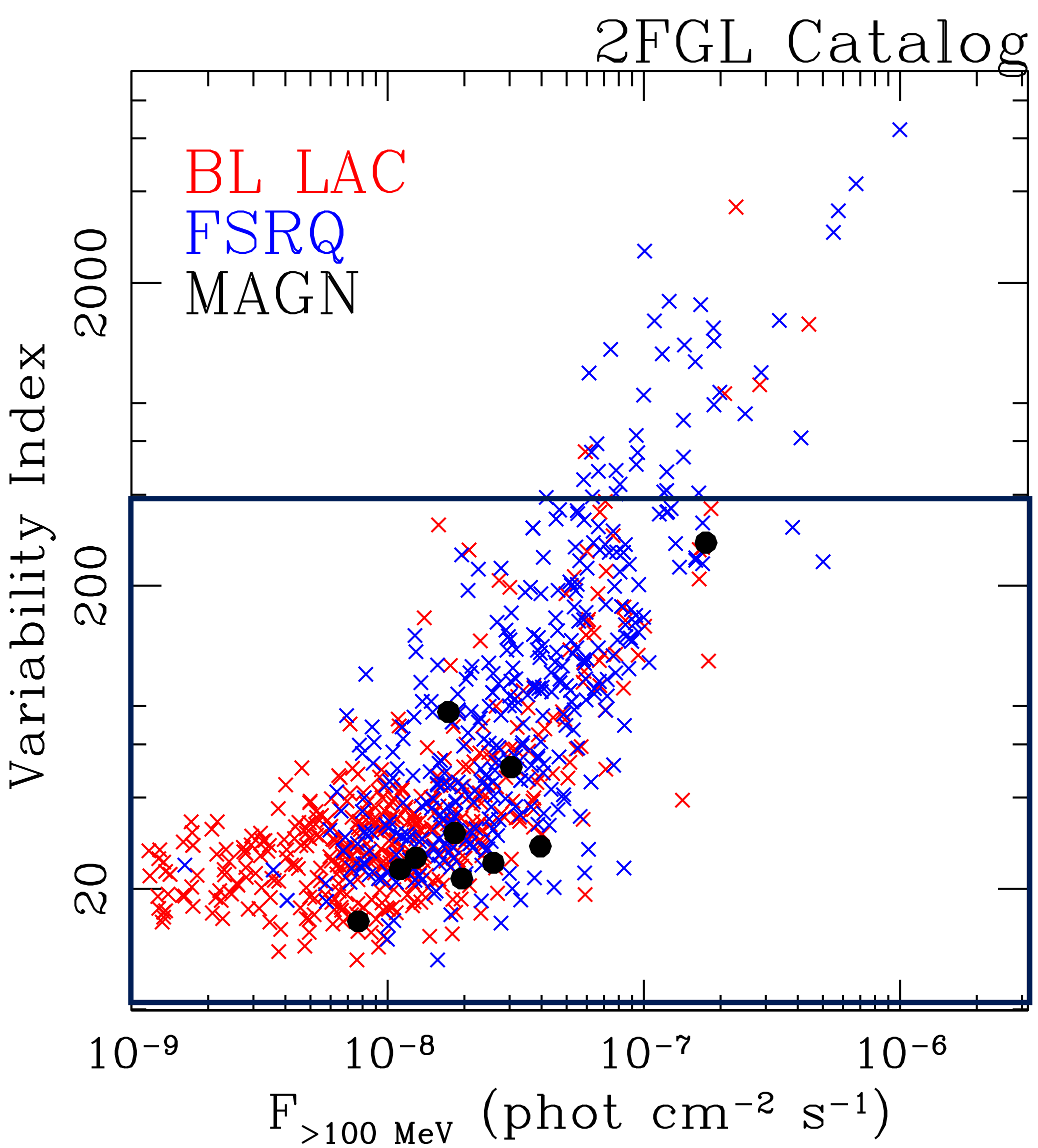
2FGL Variability Index



The variability index (Var Index) is an indicator of the source variability on time scale of months

An index > 41.6 indicates a >99% confidence probability that the source is variable.

2FGL Variability Index



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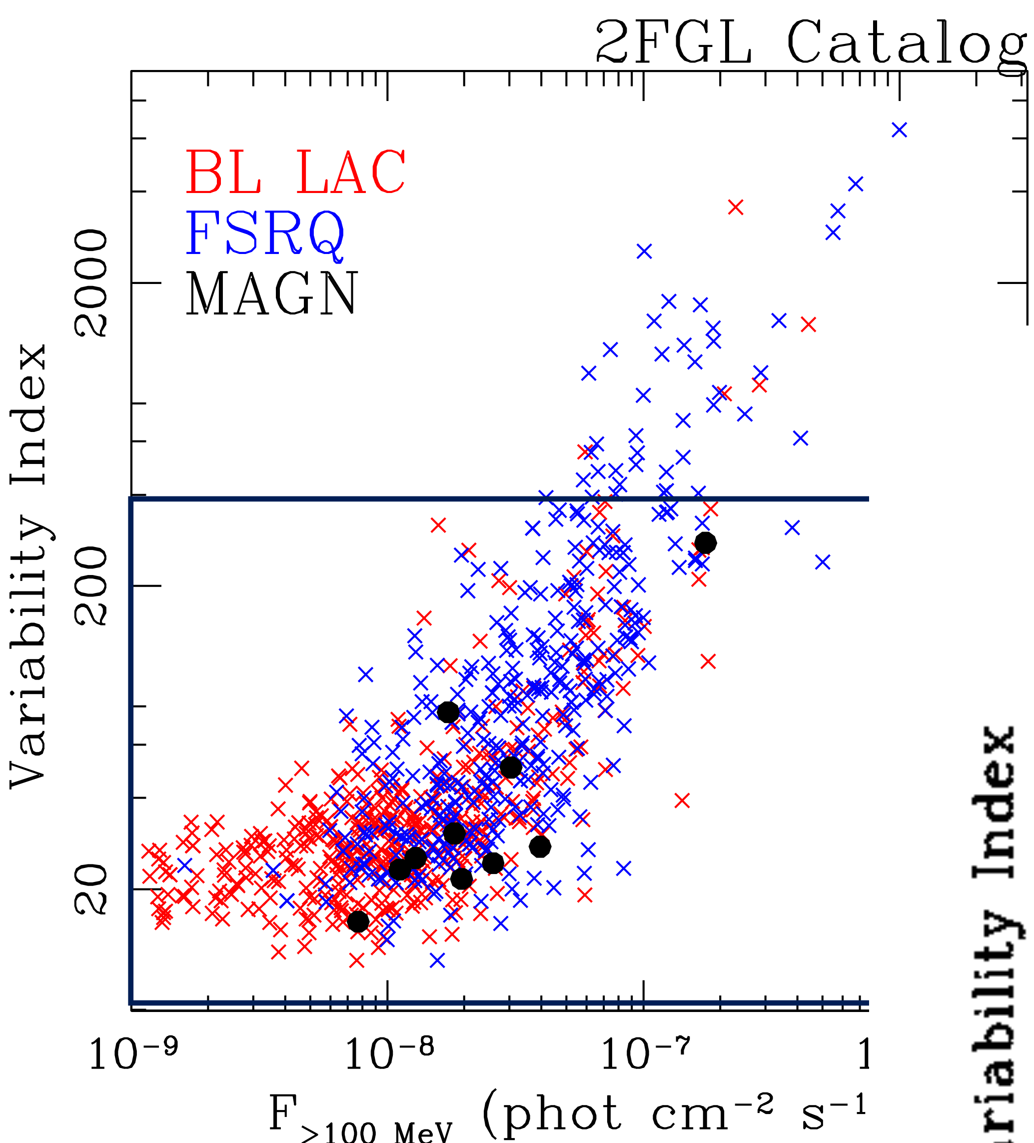

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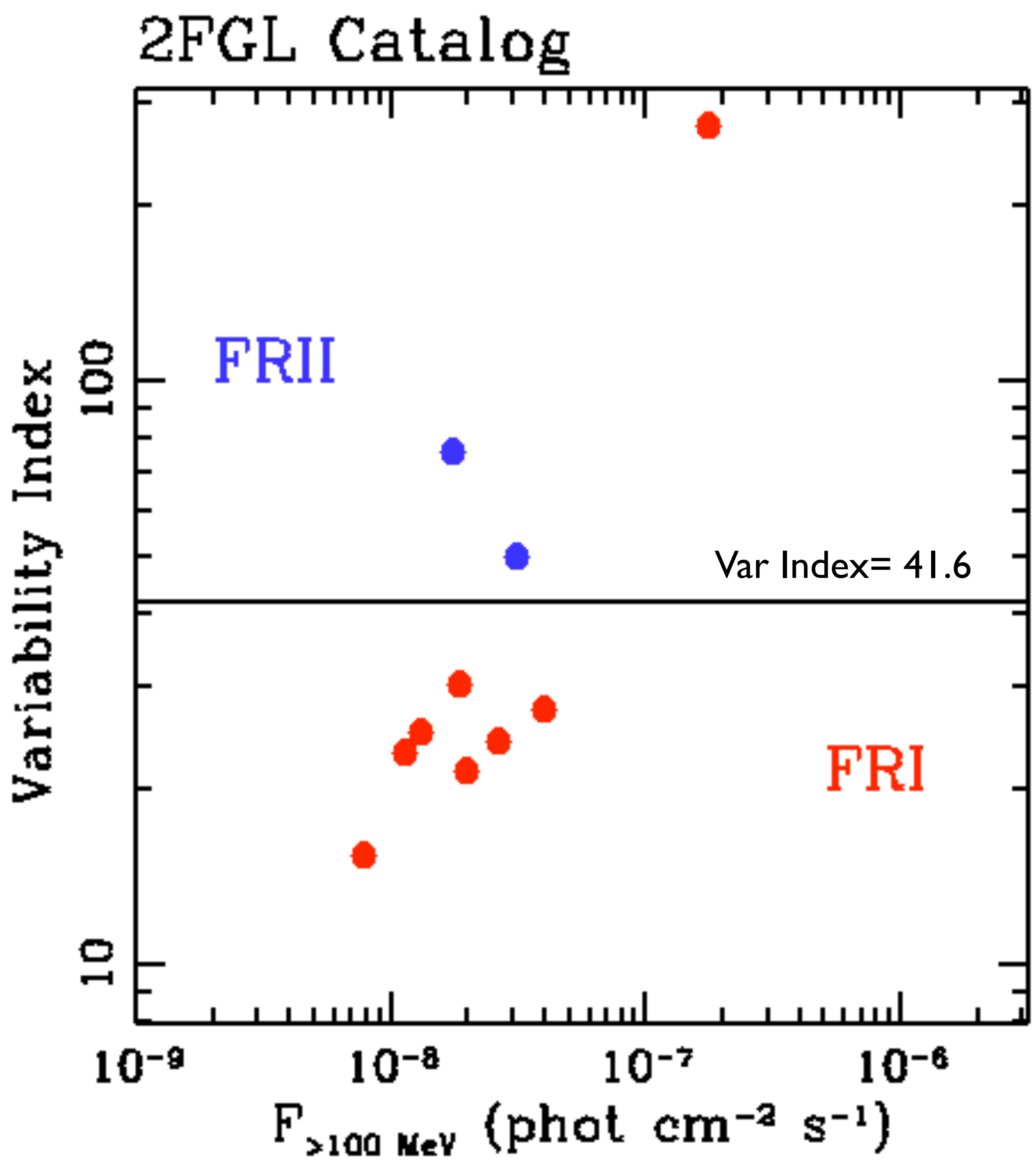
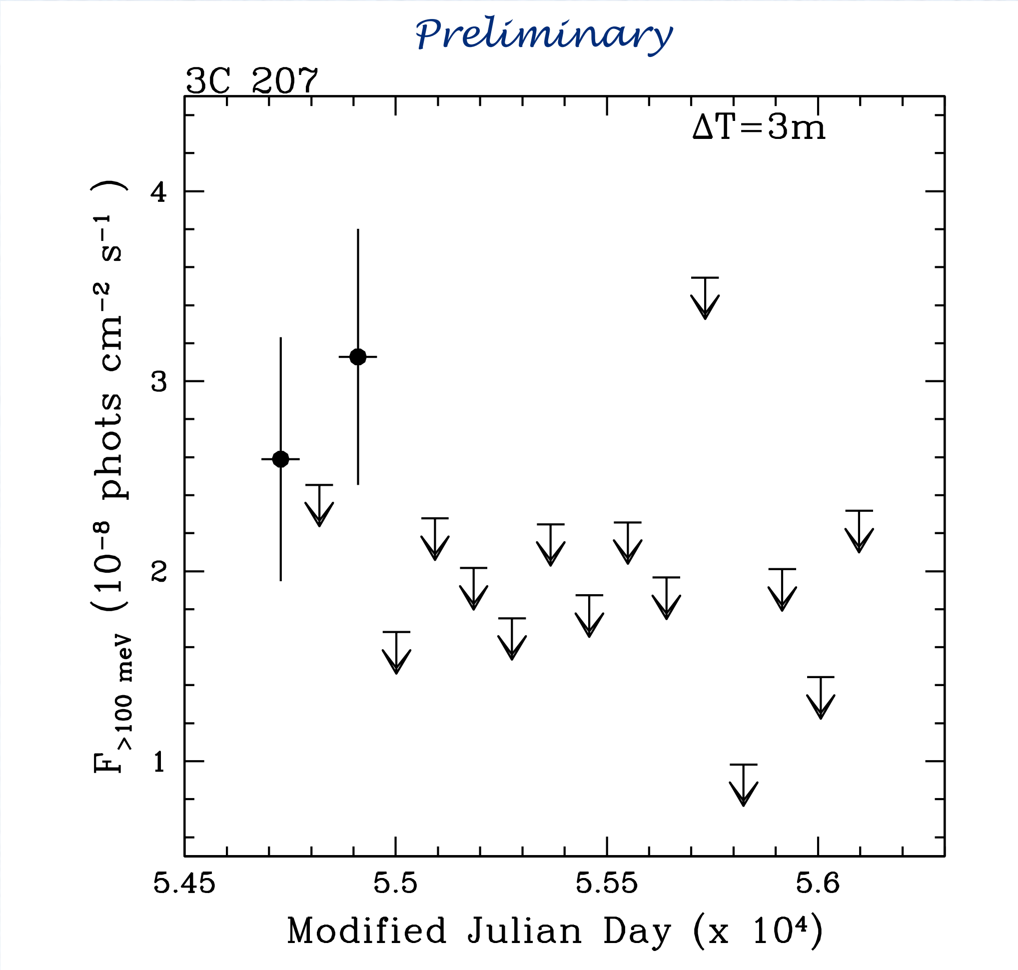
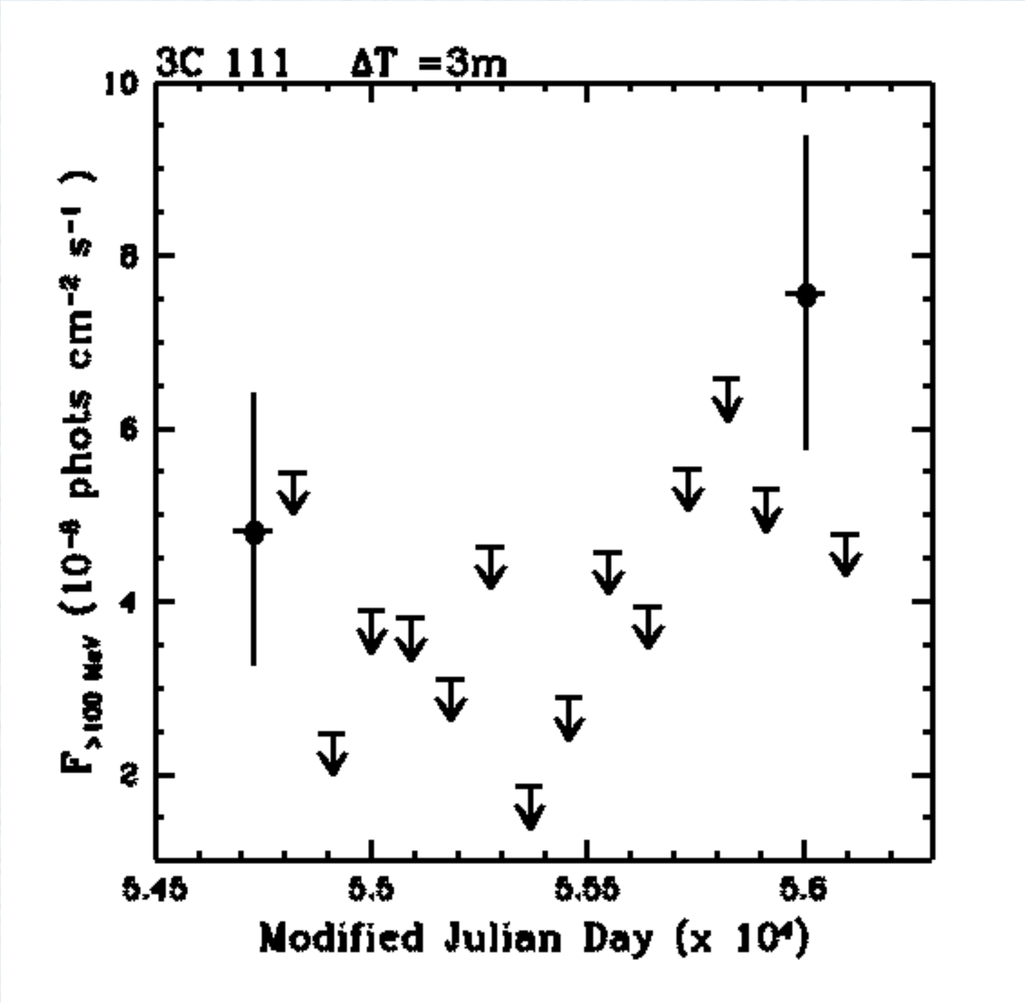


Preliminary

FRII

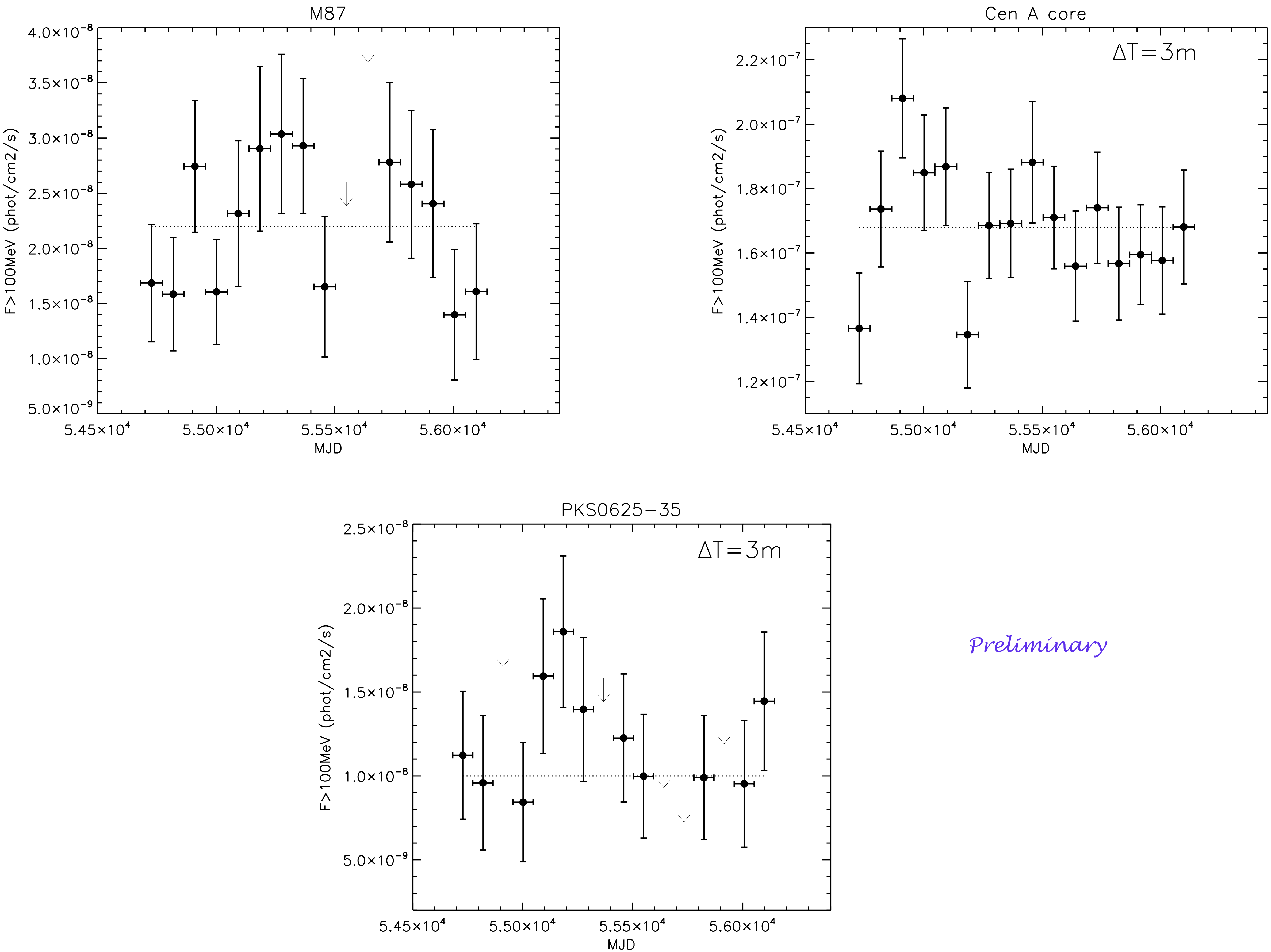




Intense and rapid flares

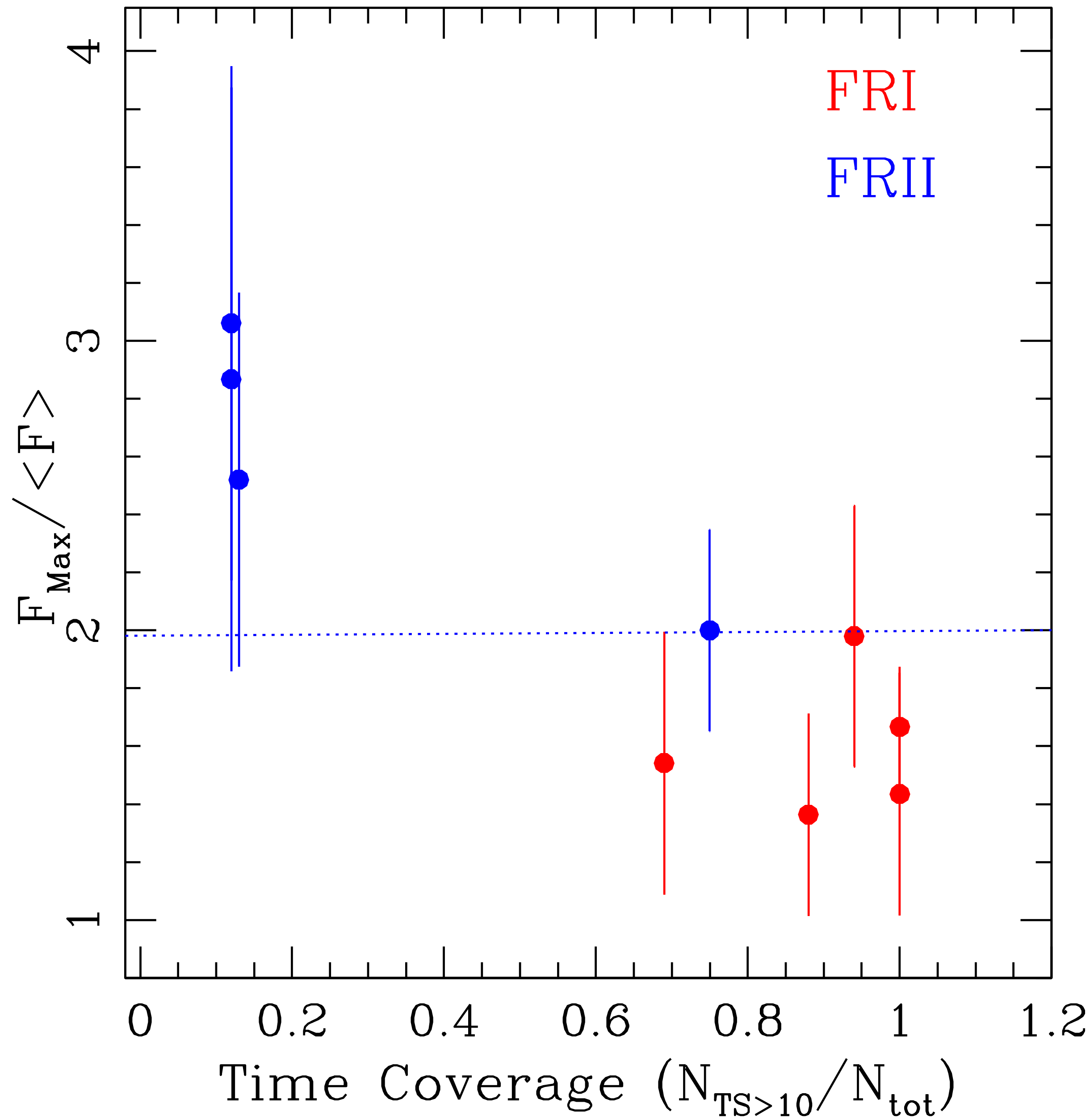
see Torresi's talk

FRI Radio Galaxy

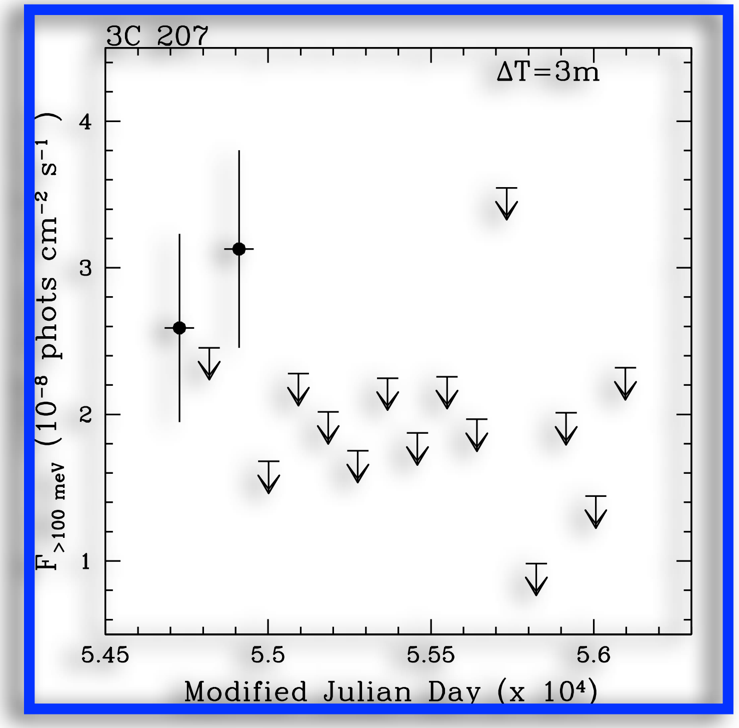


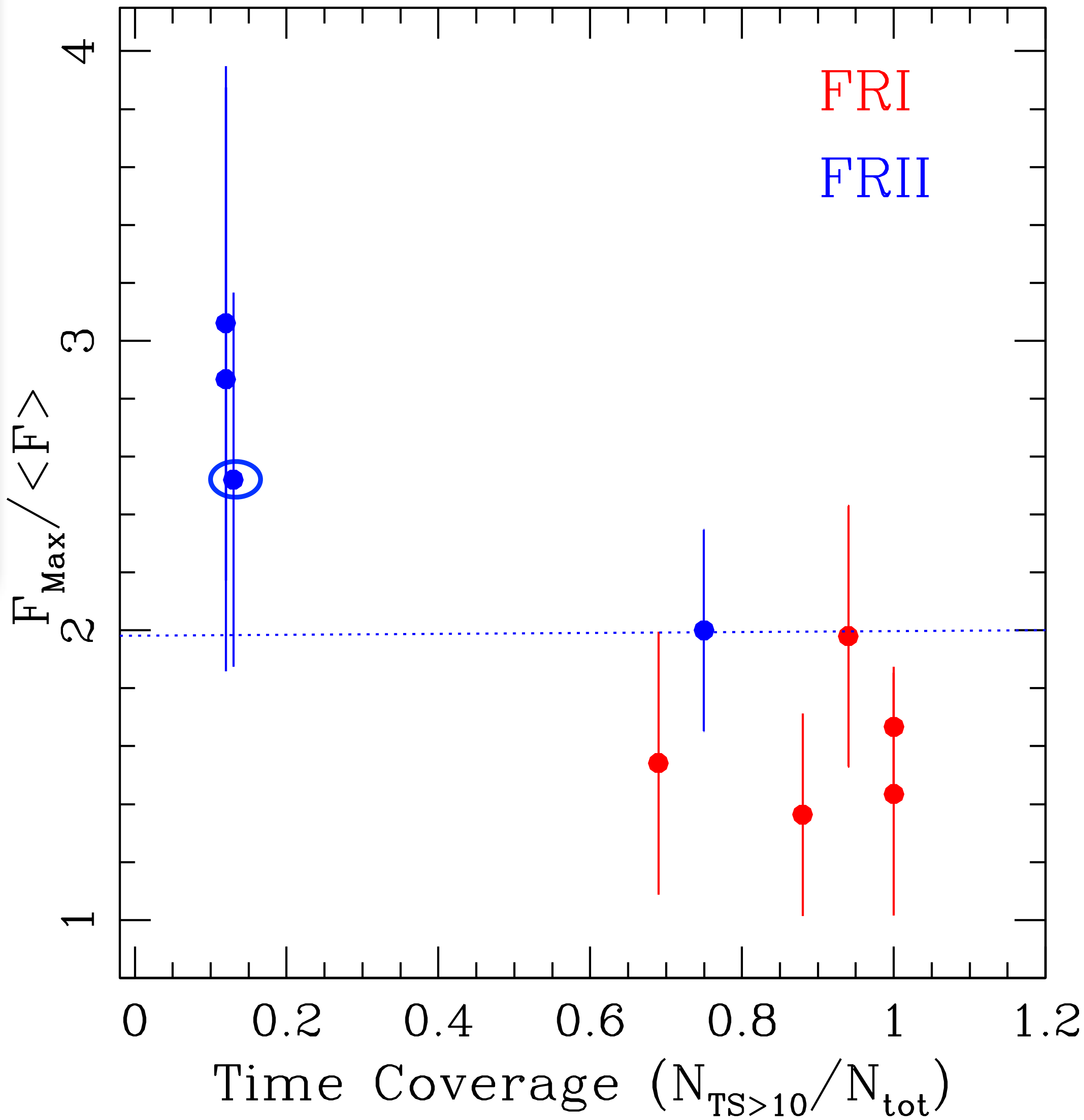
Preliminary

FRIIs have generally lower time coverage, but higher ratio F_{Max}/<F> than FRI



FRIIs have generally lower time coverage, but higher ratio $F_{Max}/\langle F \rangle$ than FRI





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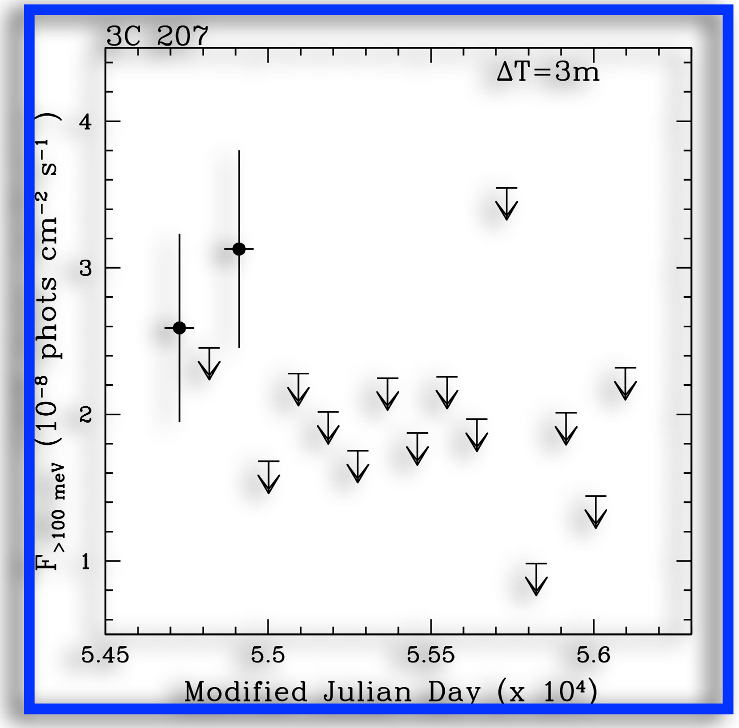
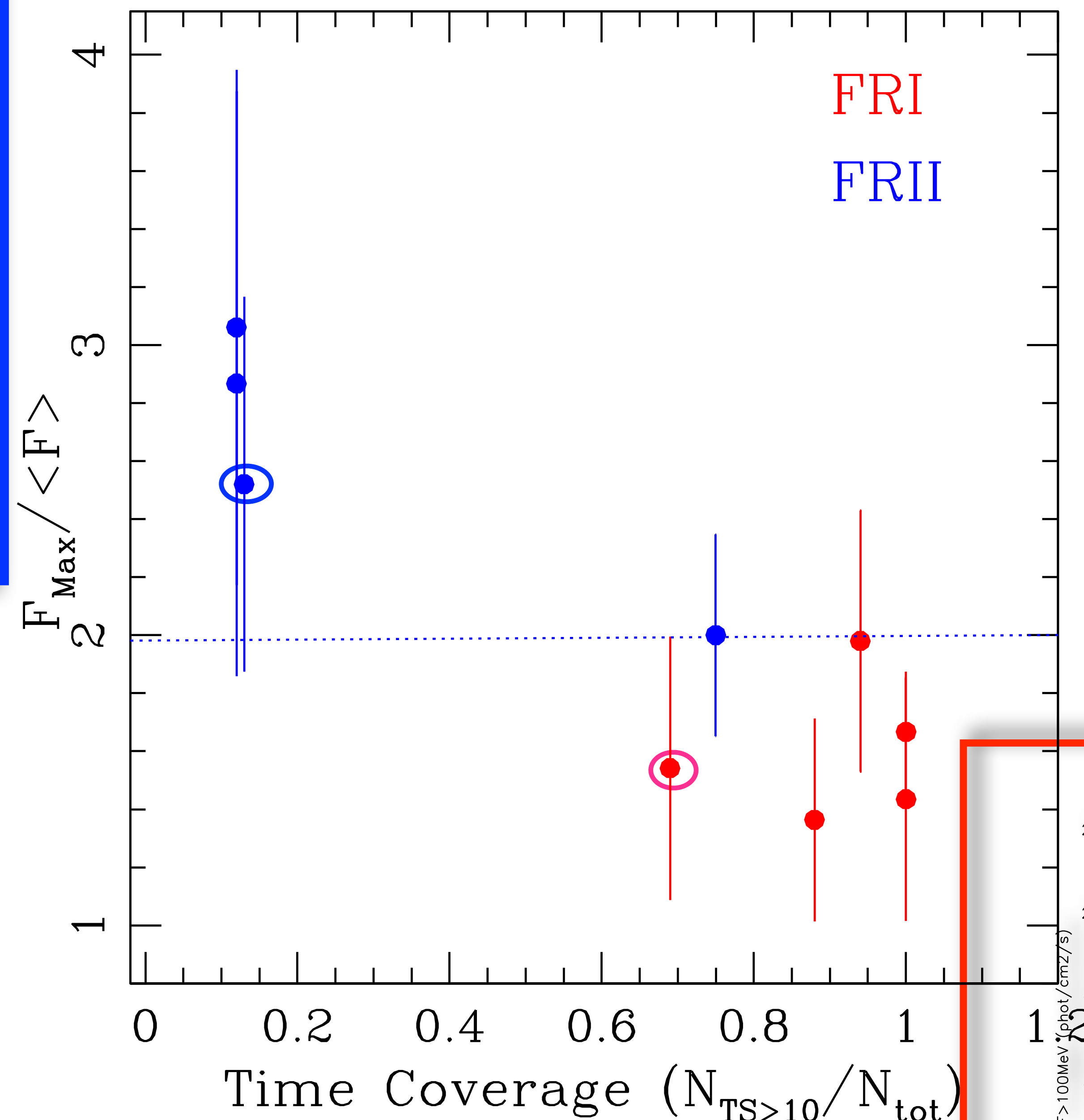
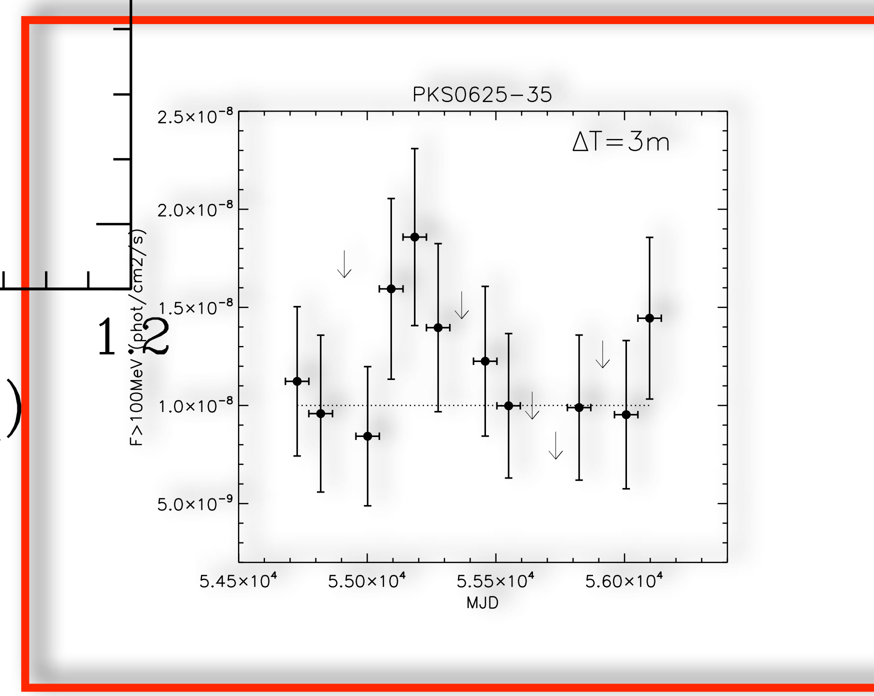
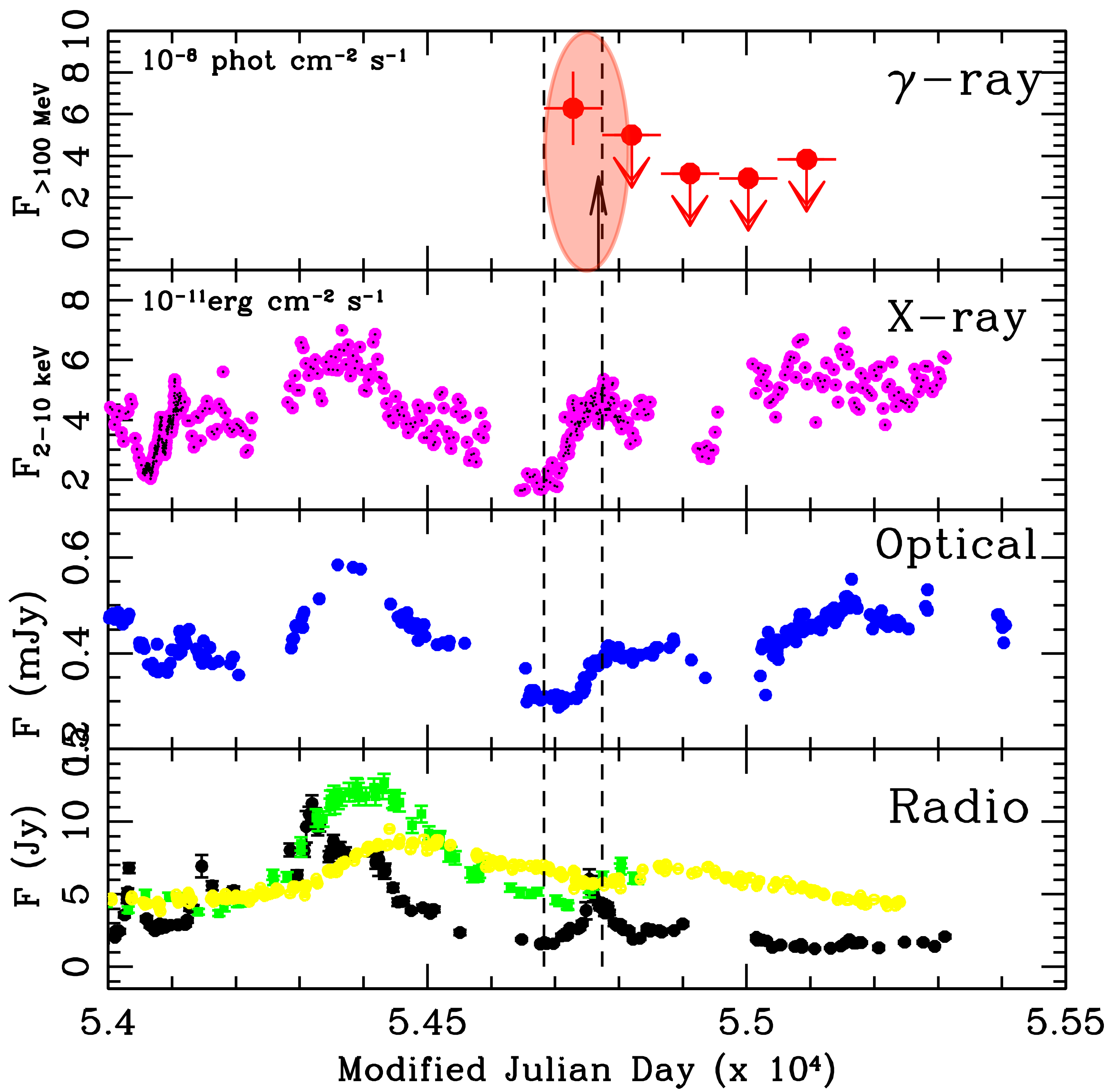
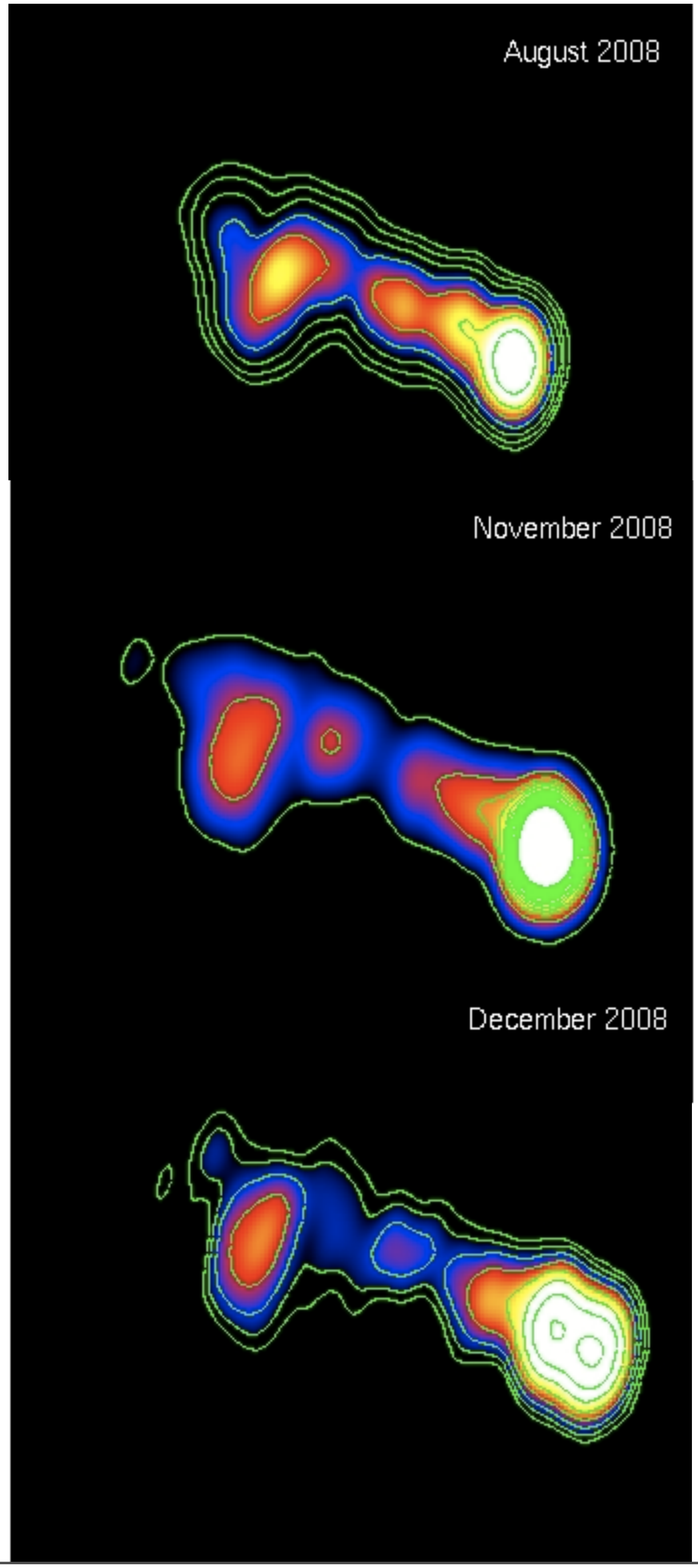






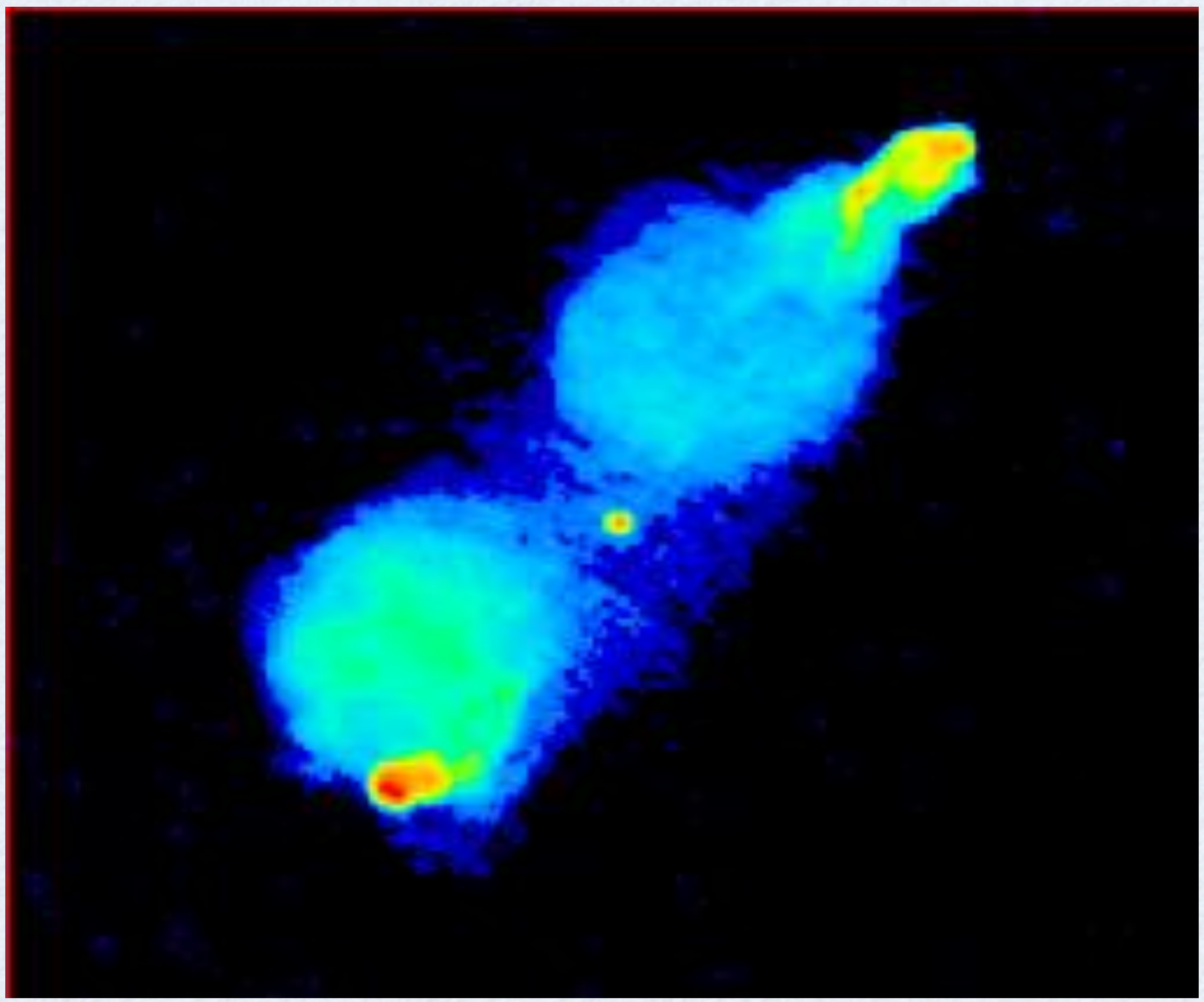
3C111 FRII BLRG
γ-ray coming from the radio core





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

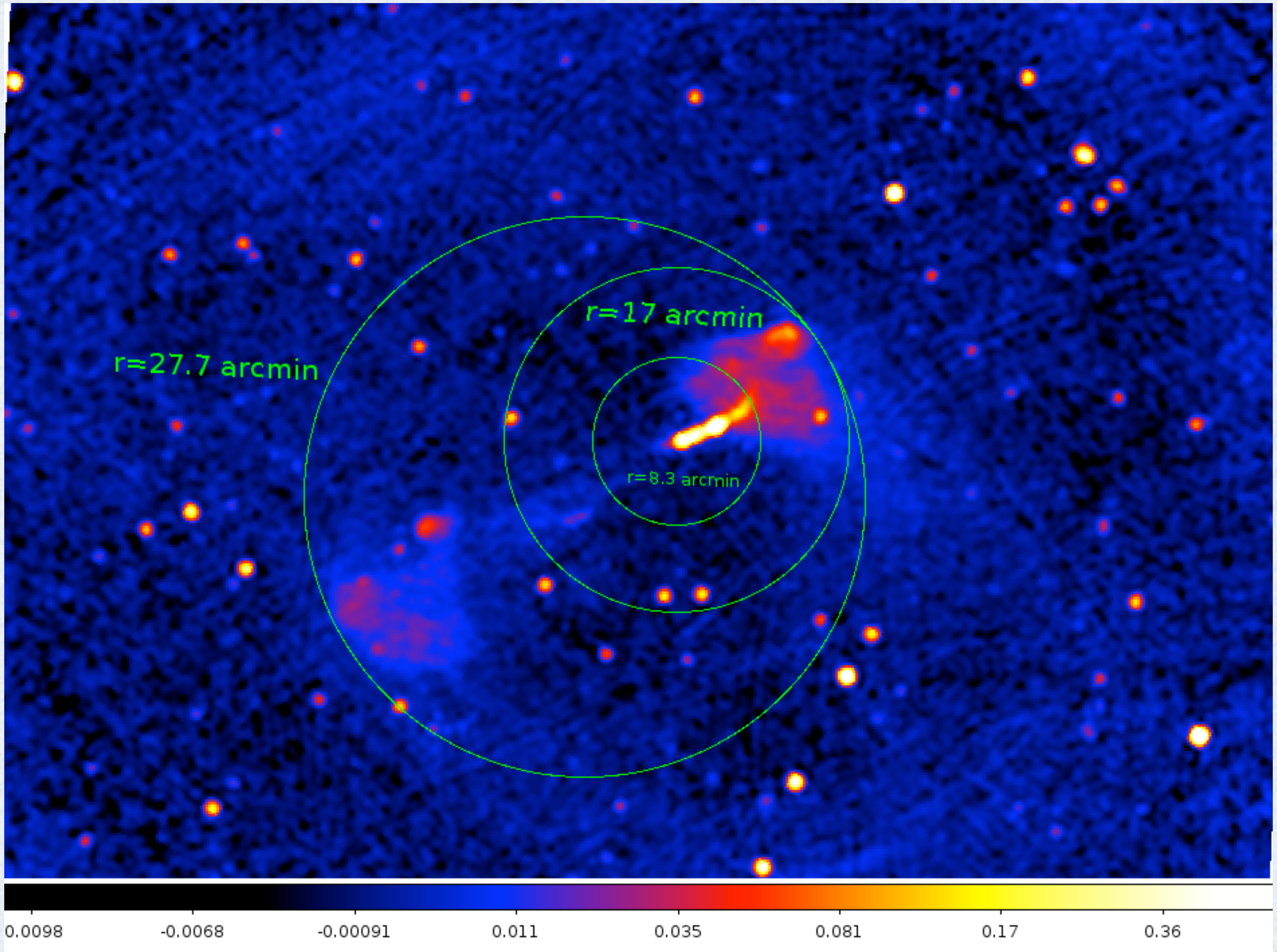
FRII GeV variability



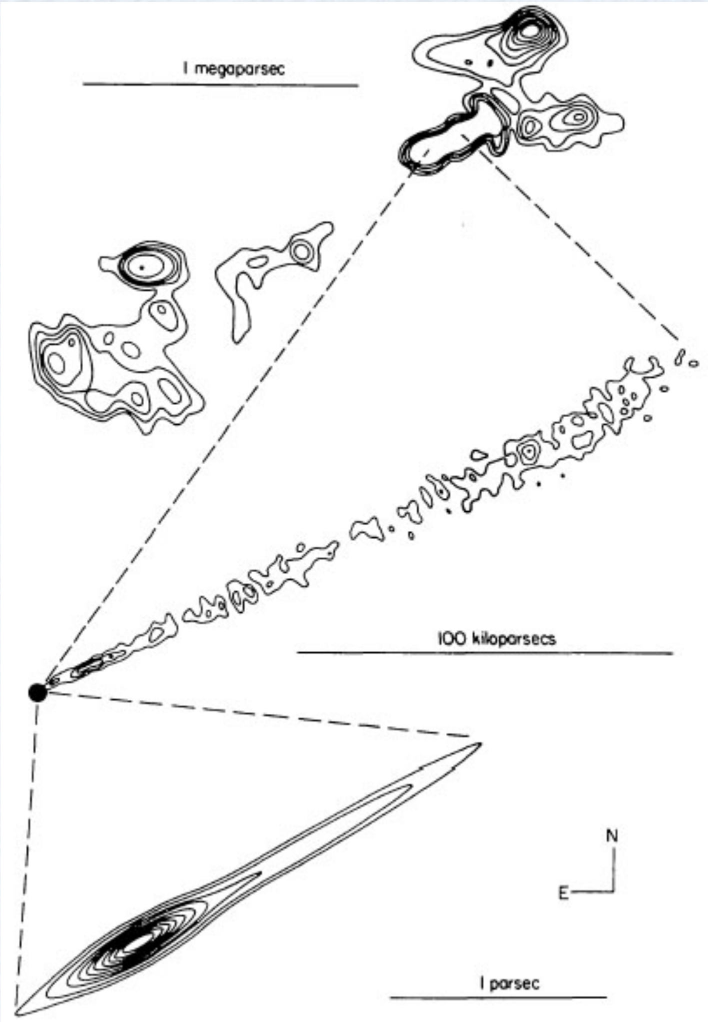
compact size (light-months or less) for high energy photons' dissipation regions;

location sub-pc region (radio core)

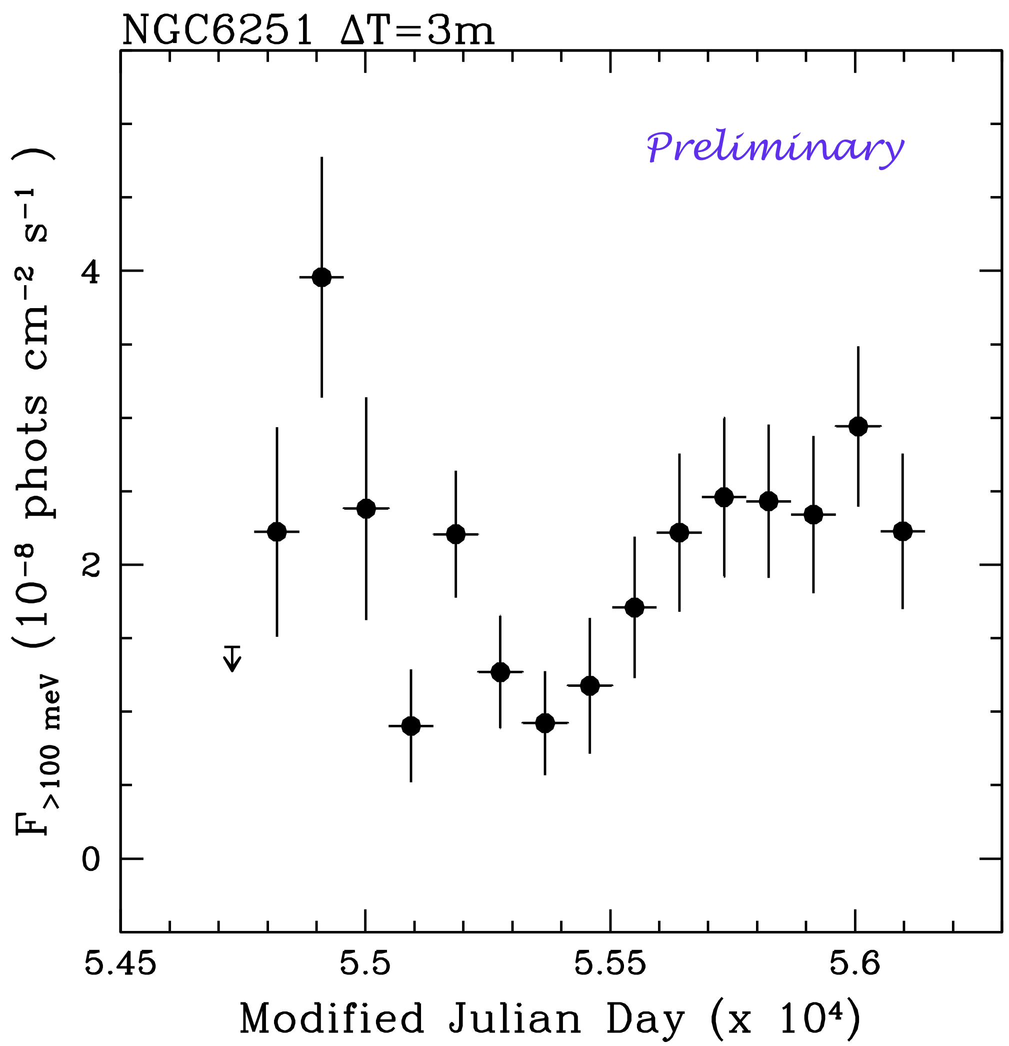
FRI NGC6251



z=0.0244   1" ~ 500 pc



P_{χ^2} (constant) ~2×10^{-3}

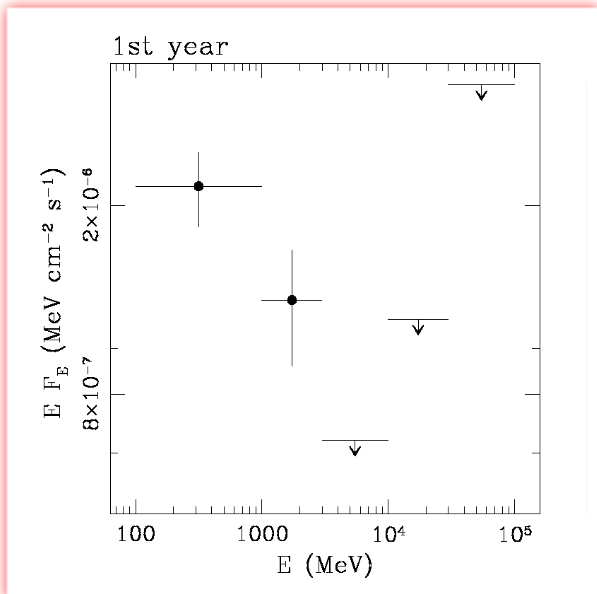


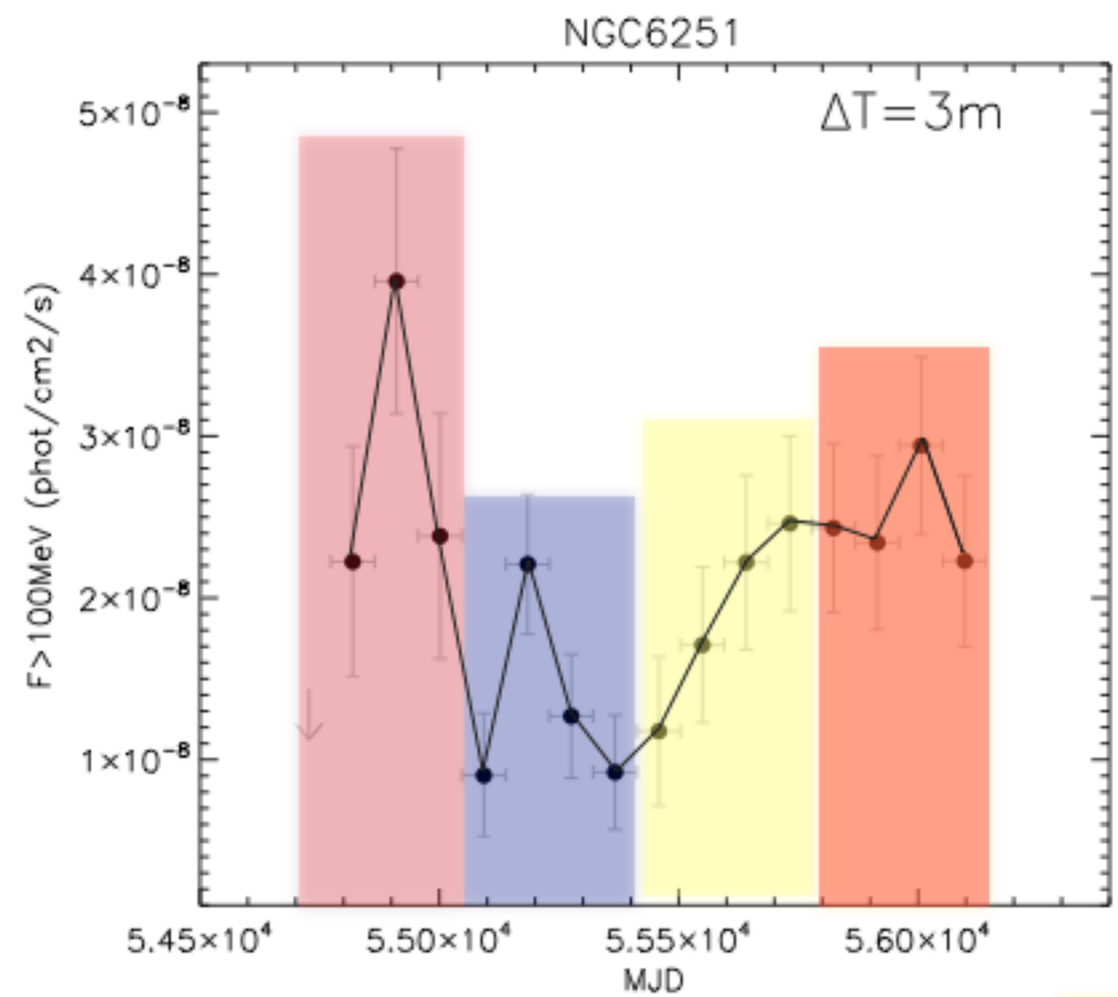
The flux doubles
in about 6 months
the flaring source is
compact

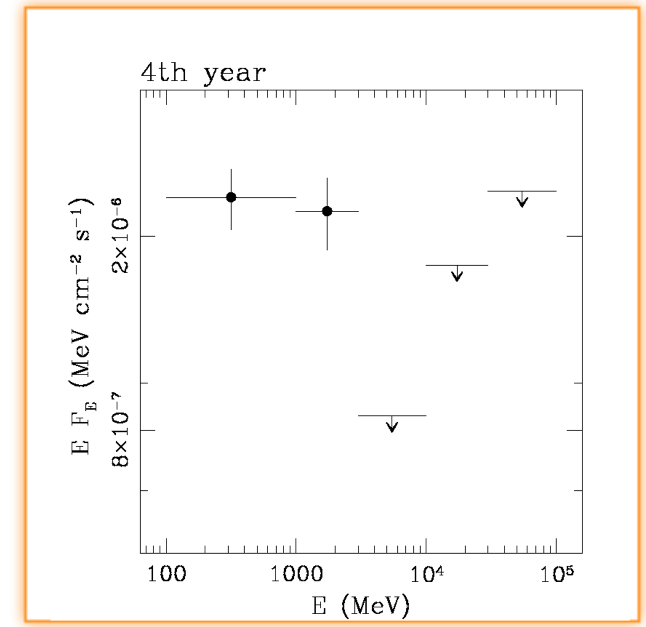
$$R \leq \frac{\Delta t \times c \times \delta}{1+z} \sim 0.06 \times \delta \leq 0.15 \text{ pc}$$

Preliminary

1st year

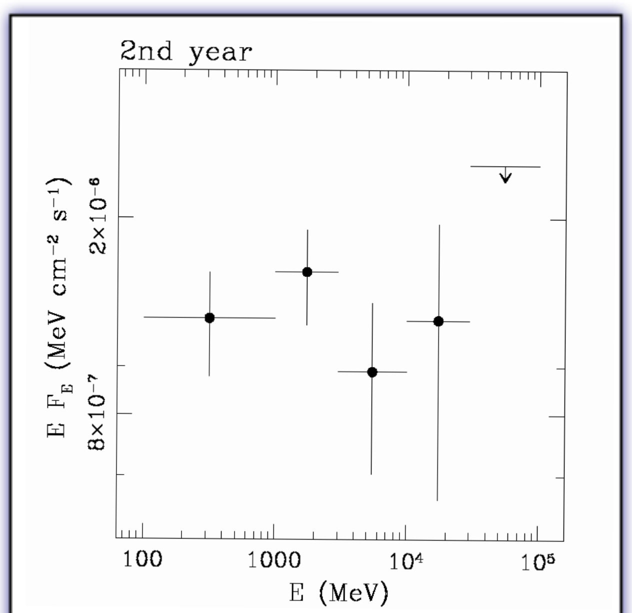




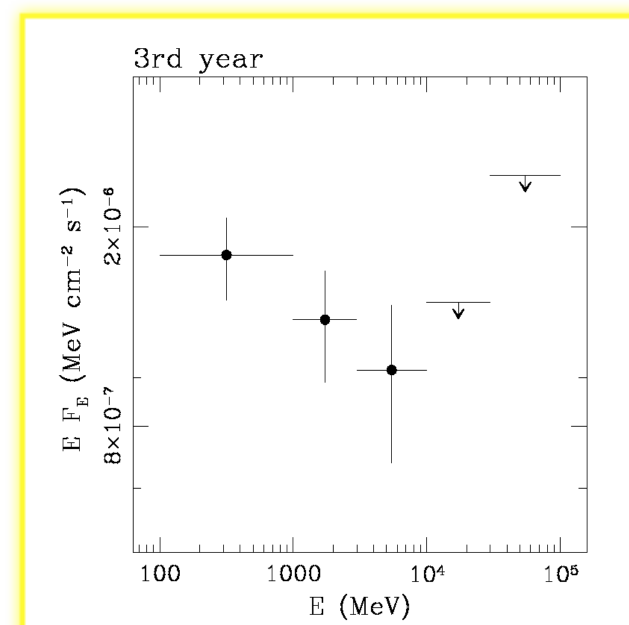


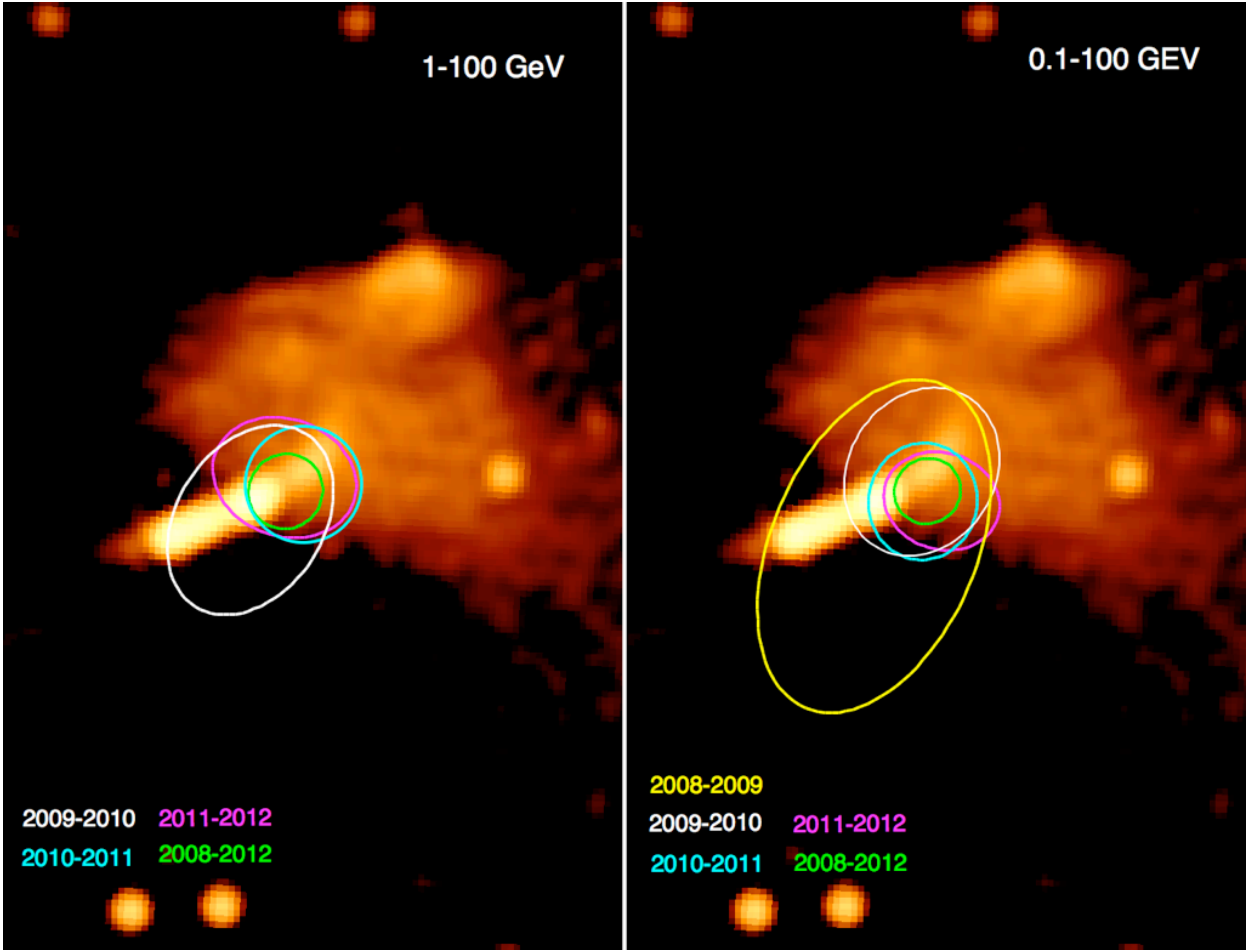
4th year

2nd year



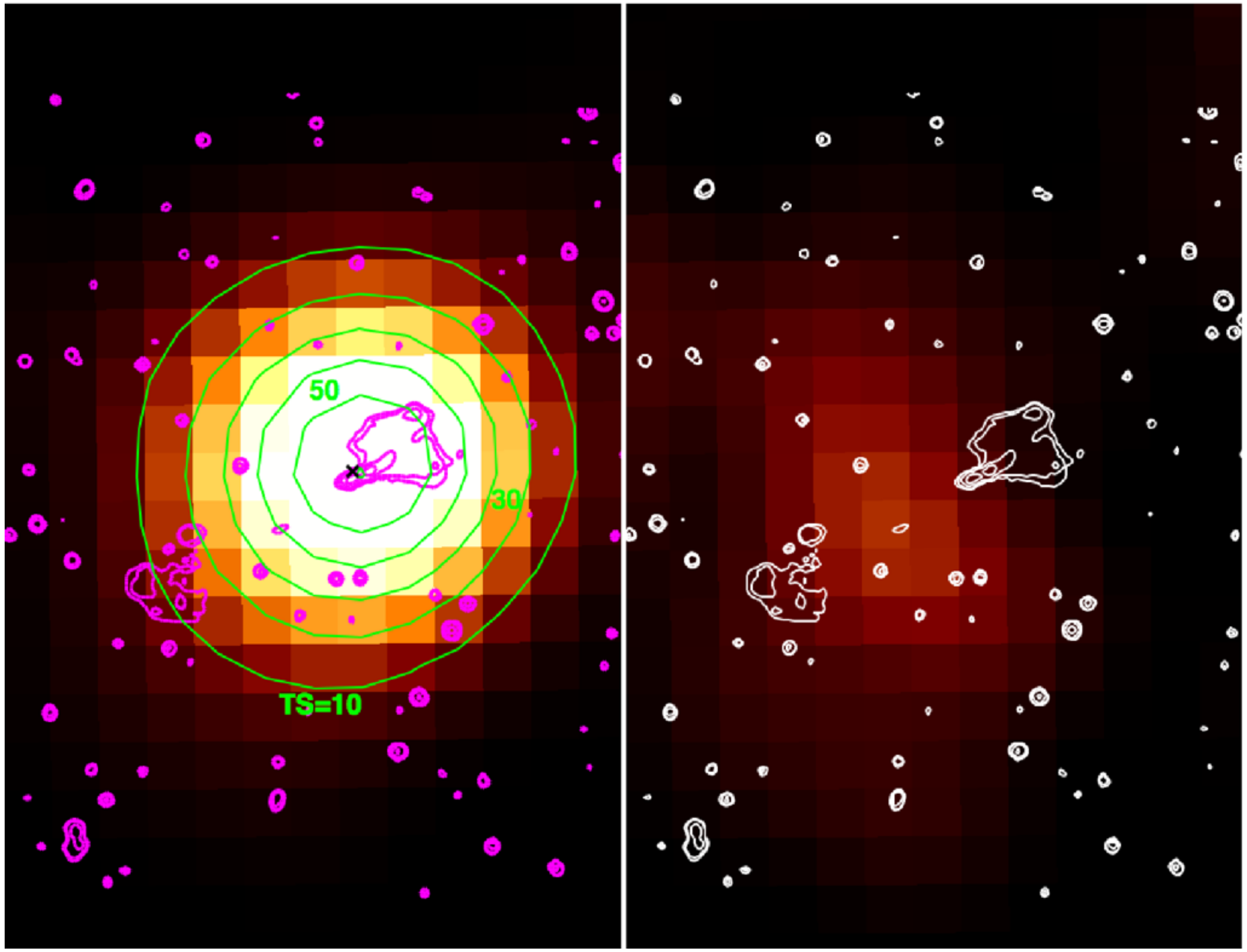
3nd year





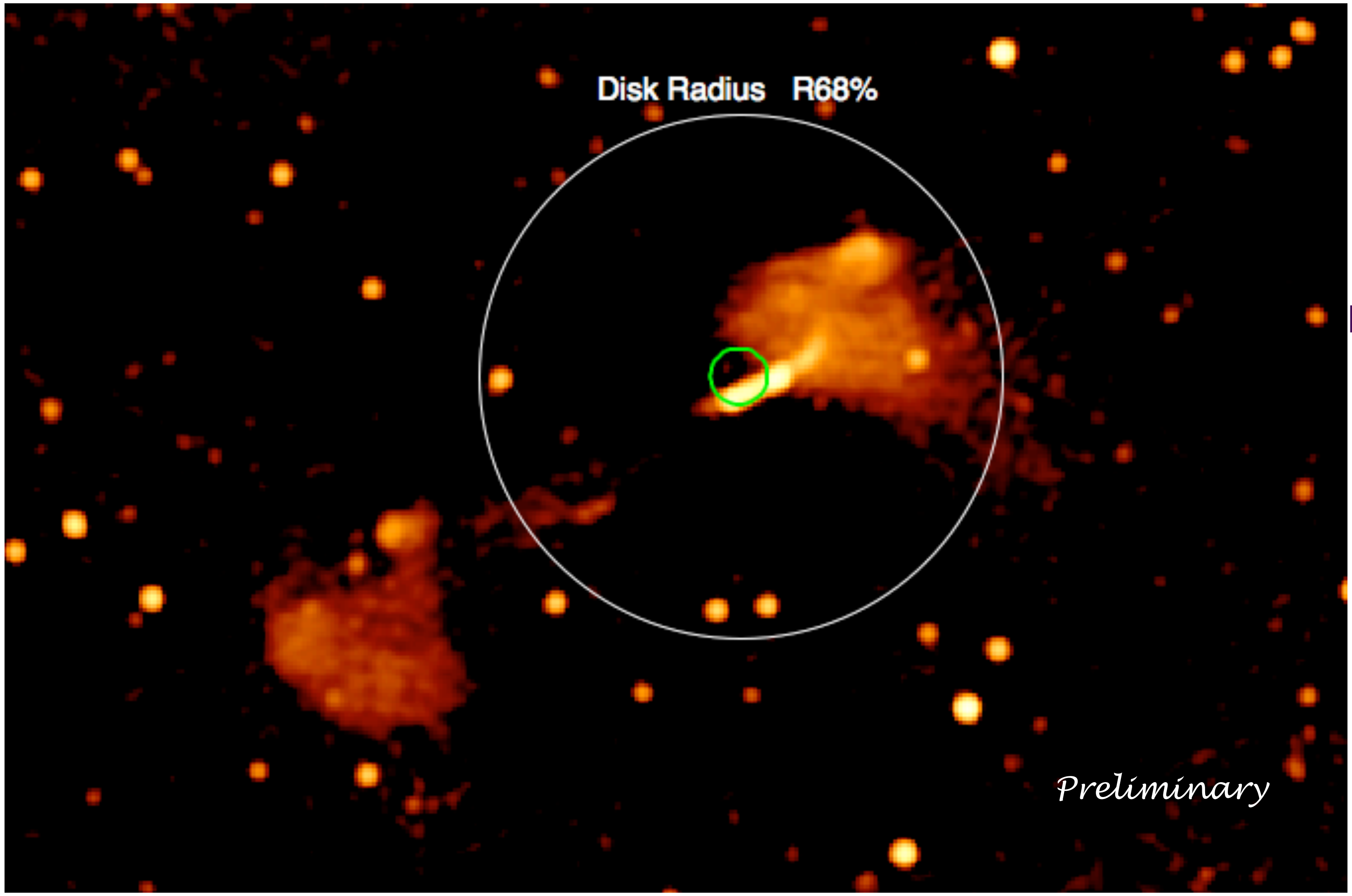
Preliminary

Preliminary

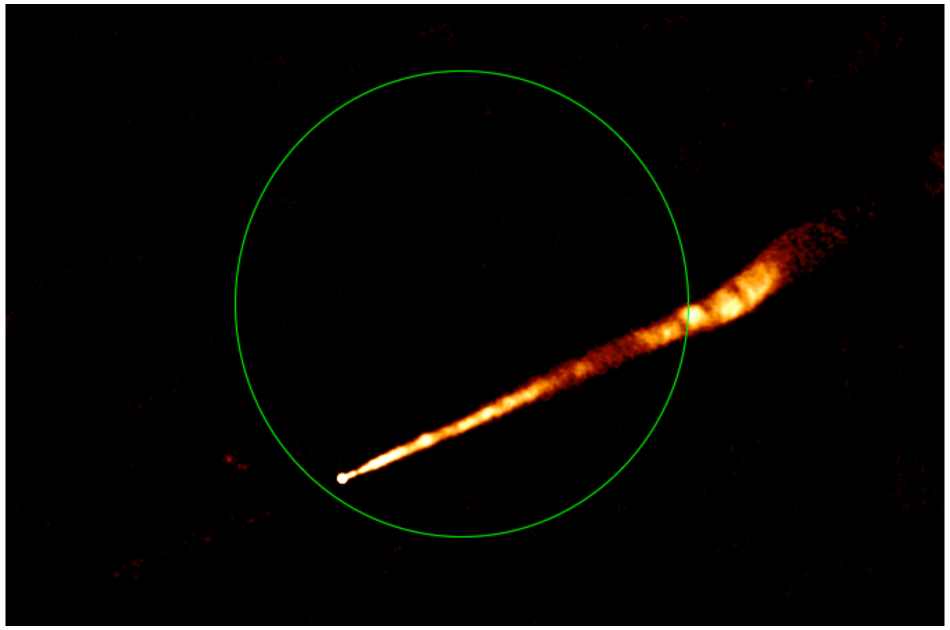


After subtracting NGC6251
(assumed to be pointlike)
TS map shows residuals

Indication that the $\gamma-$ray source is extended



Modeling the source as a disk
R_68% ~ 0.30 degrees



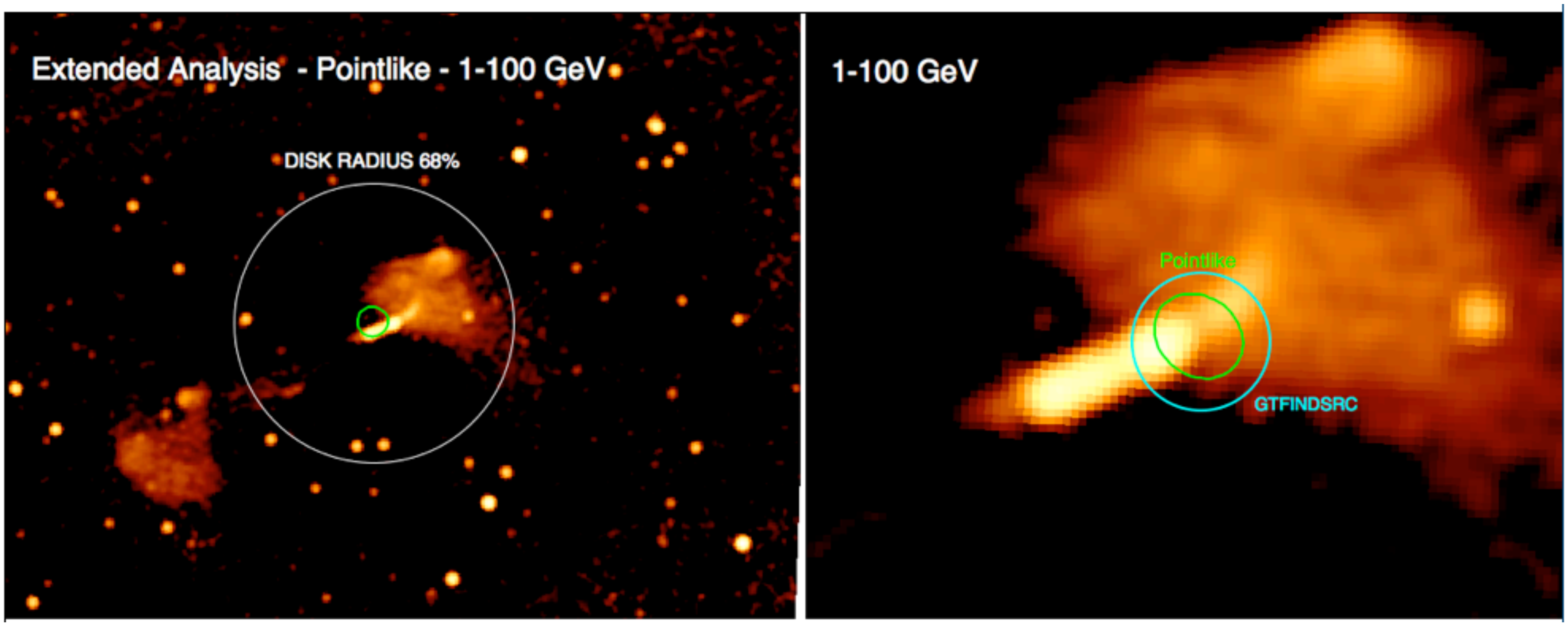
The best localization of the region now included the radio core

Two possible data interpretations

There are multiple gamma-ray emission regions

radio core driving the time variability
+
an extended component
(lobe- knots along jet?)

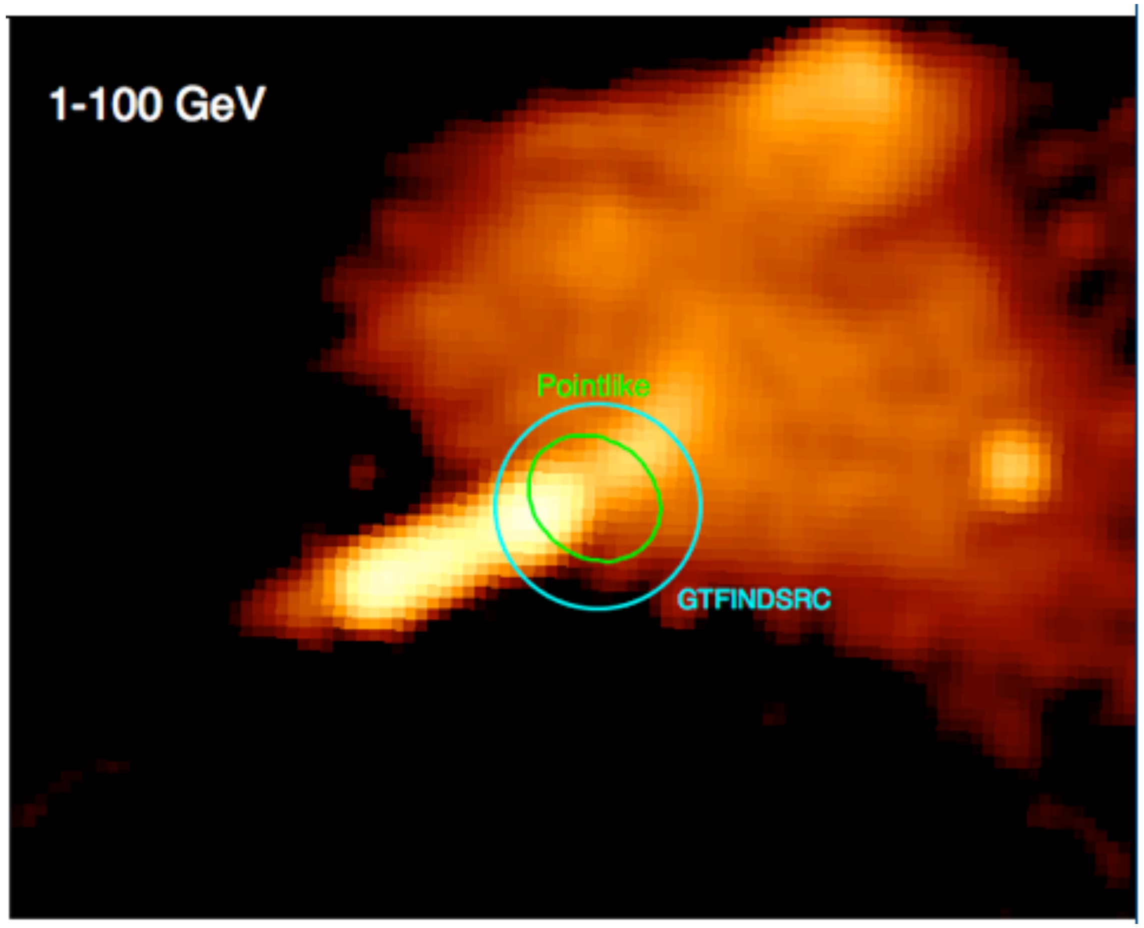
There is a unique detectable gamma-ray source
on the jet but not coincident with the radio core



Strong component on the jet

☑ Gamma-ray analysis performed with two different tools using 48 months of data unequivocally indicates that the peak of the emission is on the jet hundreds kpc away from the black hole.

☑ Splitting the total observation (48 months) in 4 segments of 1 year each, the gamma-ray emission is always localized in the same region



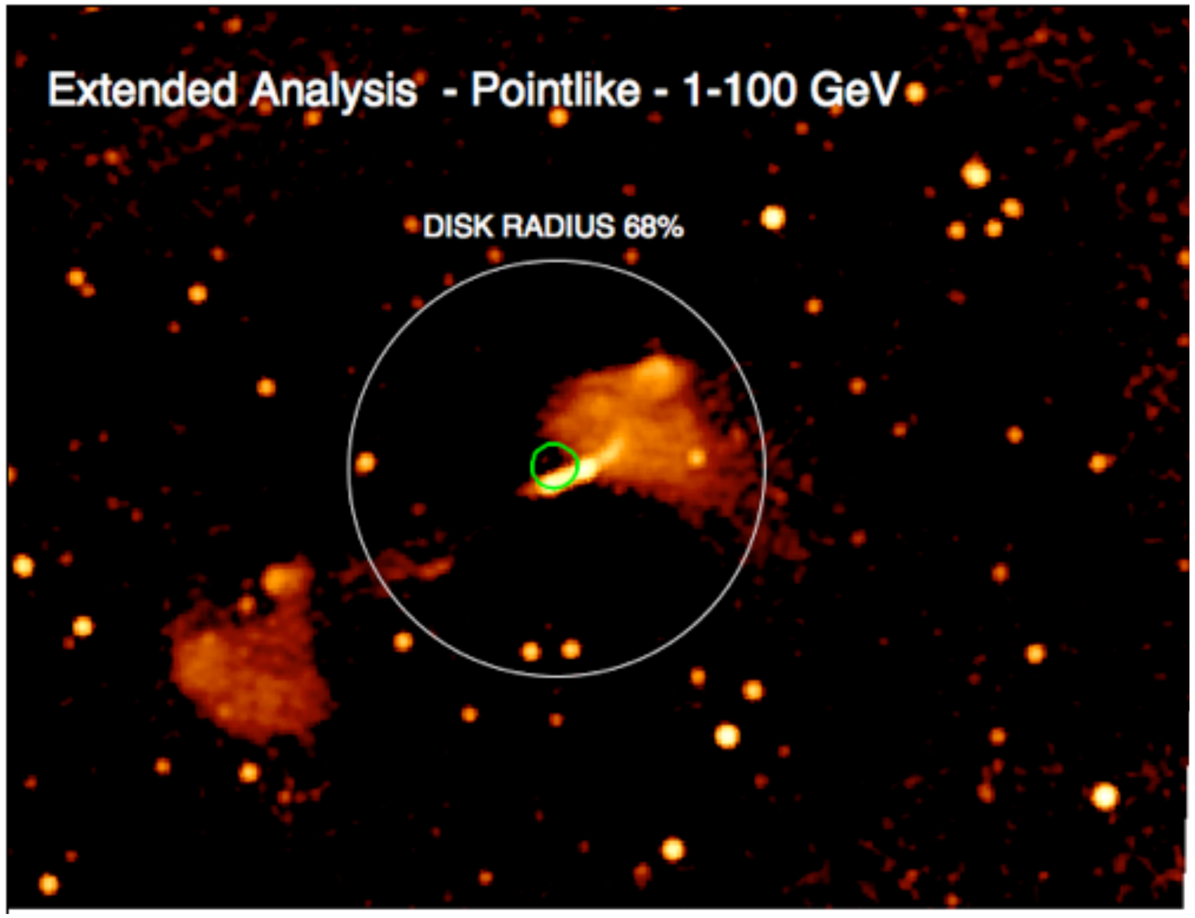
☐ Difficult to explain the presence of a strong gamma-ray variable emission at 100 kpc from the nuclear engine

The brightness of the jet varies with its width in a manner which suggests that relativistic particle reacceleration or magnetic field amplification, or both, occurs many tens of kpc from the radio core. Perley et al 1984

More than one emitting region

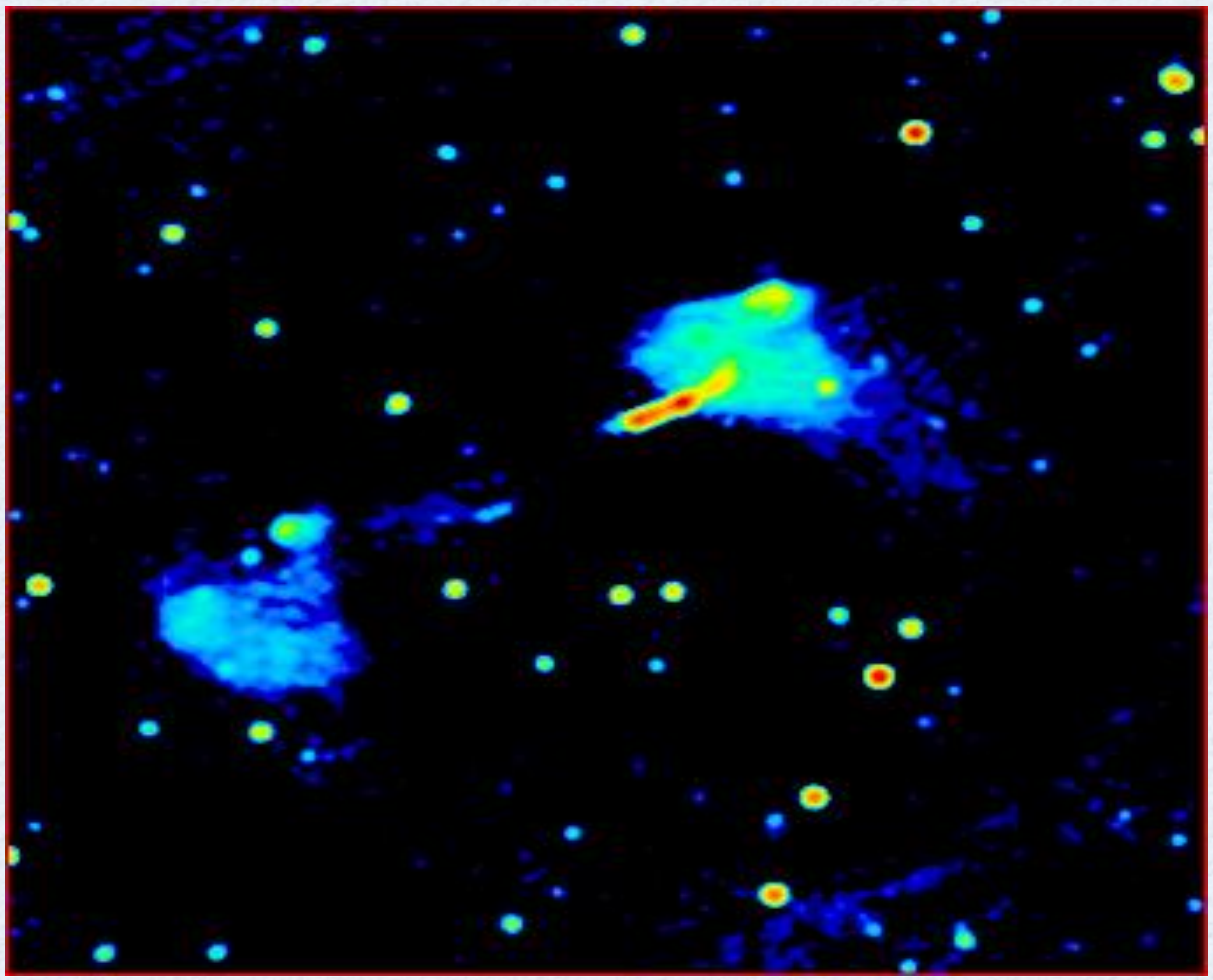
☑ The flare region is within the 68% localization circle (maybe in the radio core)

☑ The combination of radiation coming from different zones could explain the observed time and spectral variability. For example, radiation produced in an extended region could dilute the emission of a compact flaring gamma-ray source



☐ A possibile extension is statistically attested by a data analysis only restricted to the 1-100 GeV band

FR I Radio galaxy Variability



In FRIs sources the flux variations seem to be slower and less pronounced.

Multiple emission zones dilute the flare?

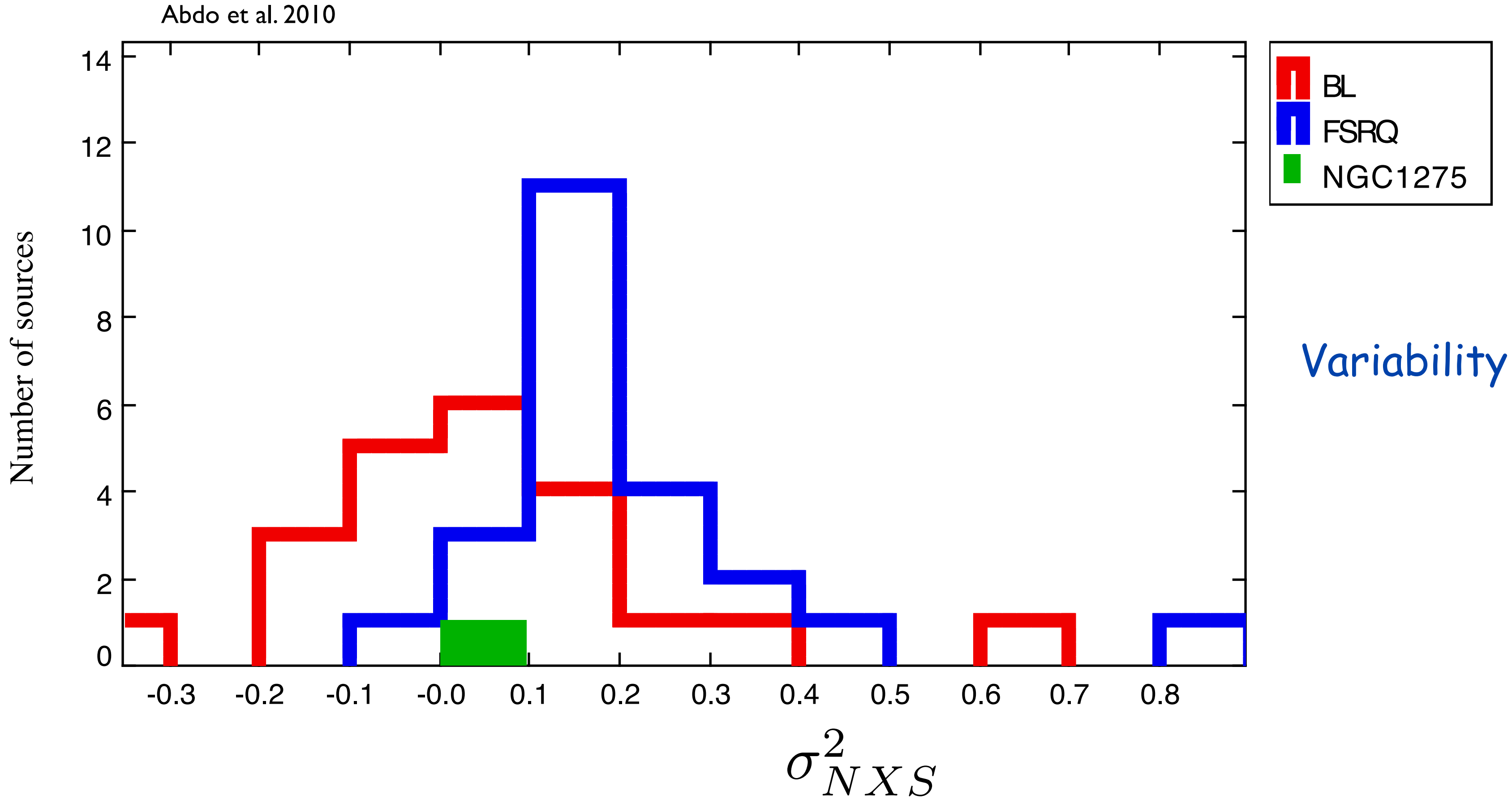
Conclusions

Variability studies indicate that:

FRIIs appear in GeV band only when an intense flare occurs, while FRIs are on average detected for the 80% of time (in 48 months considering a bin time of 3 months), but are less variable

FRIIs time variations are strong and rapid (time scale of days) and could be detected mainly during extremely intense burst (related to a radio blob ejections as suggested by 3C111)

FRIs show slow variations. Multiple emission regions?
Gamma-rays could originate both in the jet core and in an extended component as suggested by NGC6251

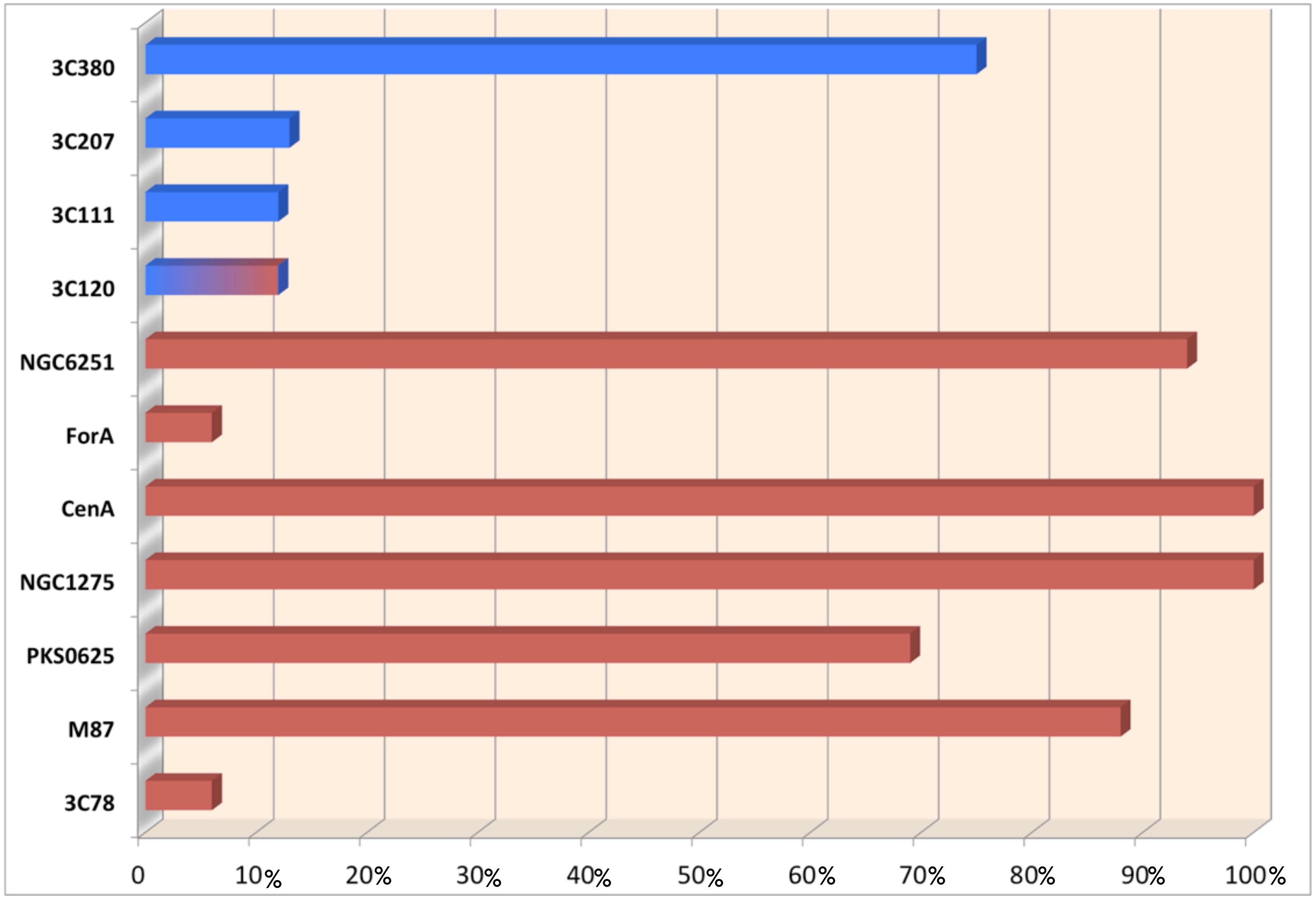


Variability study of Lat Bright AGN Sample
(106 objects)

$$\sigma^2_{NXS} = \frac{S^2 - <\sigma_{err}>^2}{<F>^2}$$

Variation amplitudes are larger for FSRQ

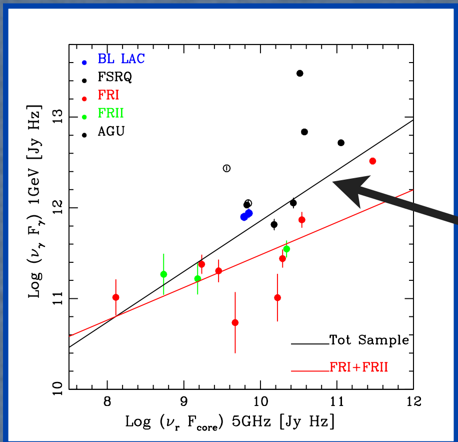
48 months of observations
light curves with bin time of 3 months



Fraction of bin with TS >10

FRIs are in average detected for the 80% of time (in 48 months considering a bin time of 3 months) but on average are less variable

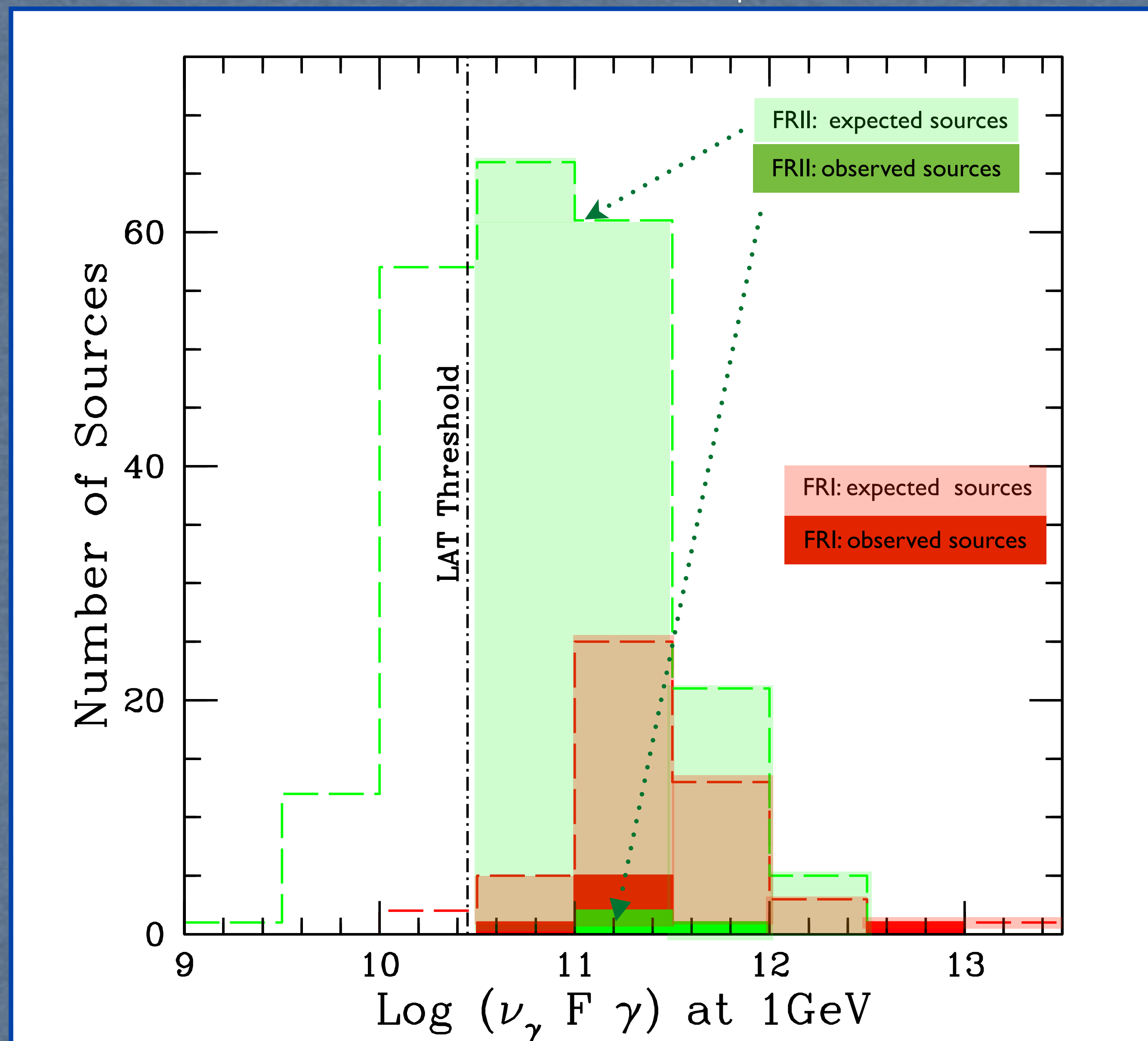
Predicted fluxes @ 1 GeV of the 3CR+3CRR+MS4+2Jy sources



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

Predicted — Observed

correlation based on the total sample

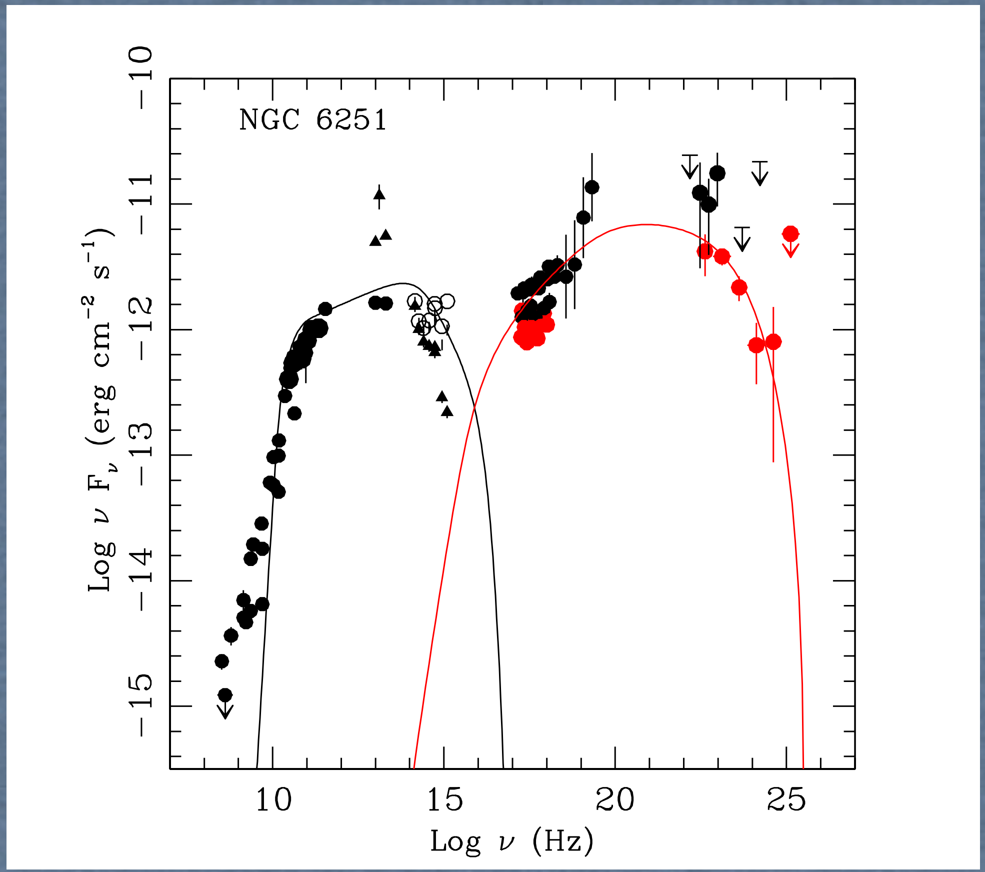


A large number of FRIIs should cross over the LAT sensitivity threshold.

In spite of this, only a handful of FRIIs is seen at GeV energies (see also Dermer & Benoit 2011)

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

After 24 months of sky survey