New insights on Misaligned AGNs in the Fermi era

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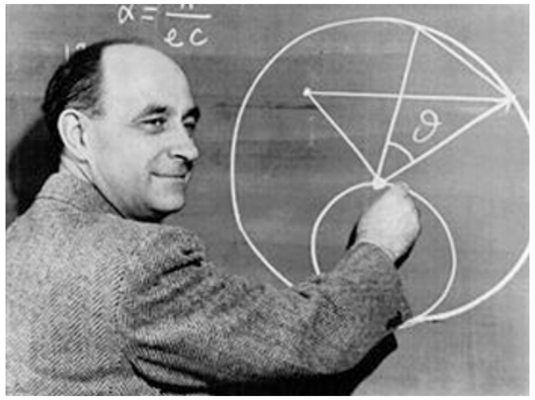
OABo/Physics & Astronomy Department Seminar, Bologna, 2013 January 10

Outline

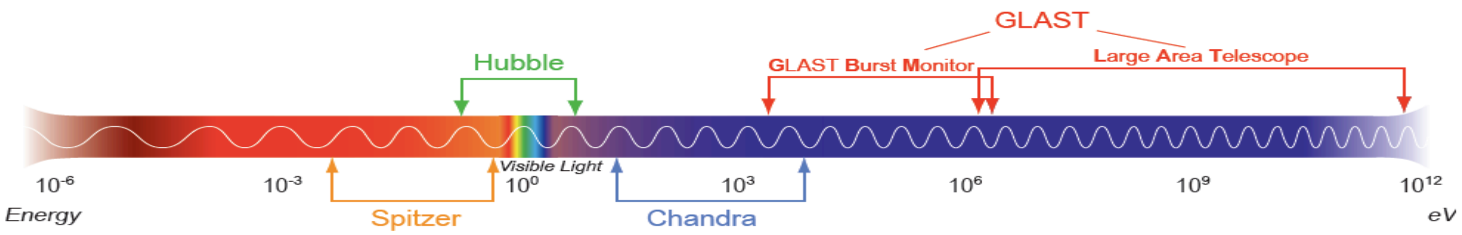
- Fermi Large Area Telescope (LAT)
- What are Misaligned AGNs (MAGNs)
- GeV properties of MAGNs
- Localization of the γ-ray emitting region
- The TANGO MW campaign

Fermi Large Area Telescope (Atwood et al. 2009)



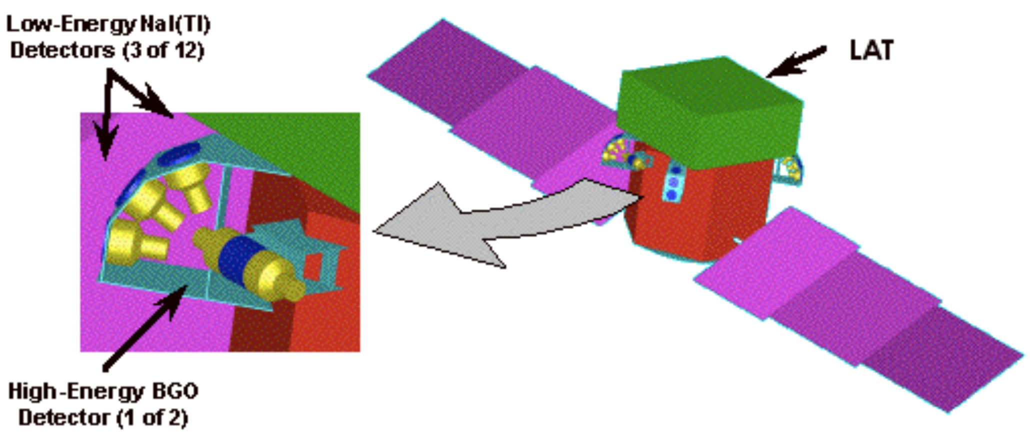
Fermi (GLAST) Gamma-ray Space Telescope

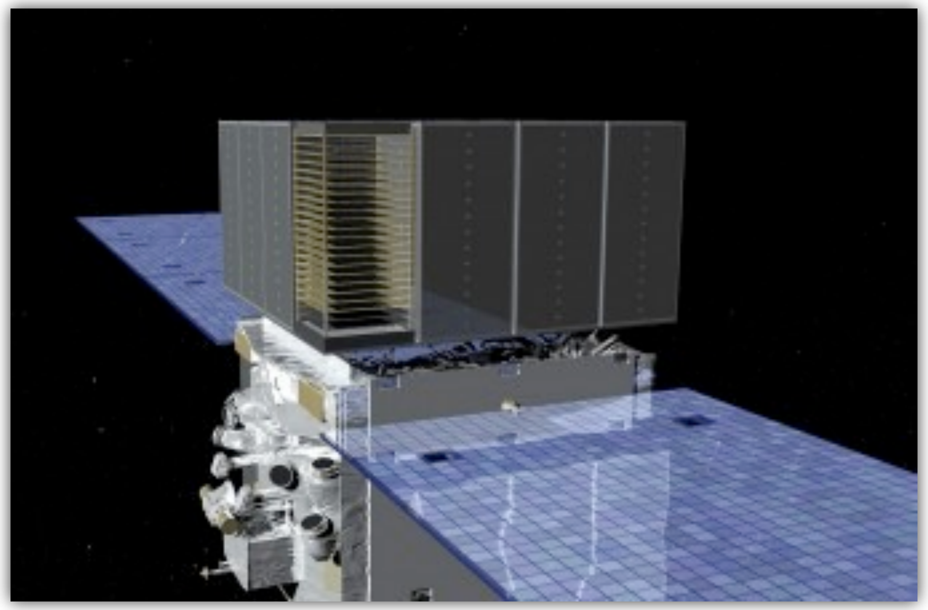
Launched on 11 June 2008



Fermi consists of two instruments:

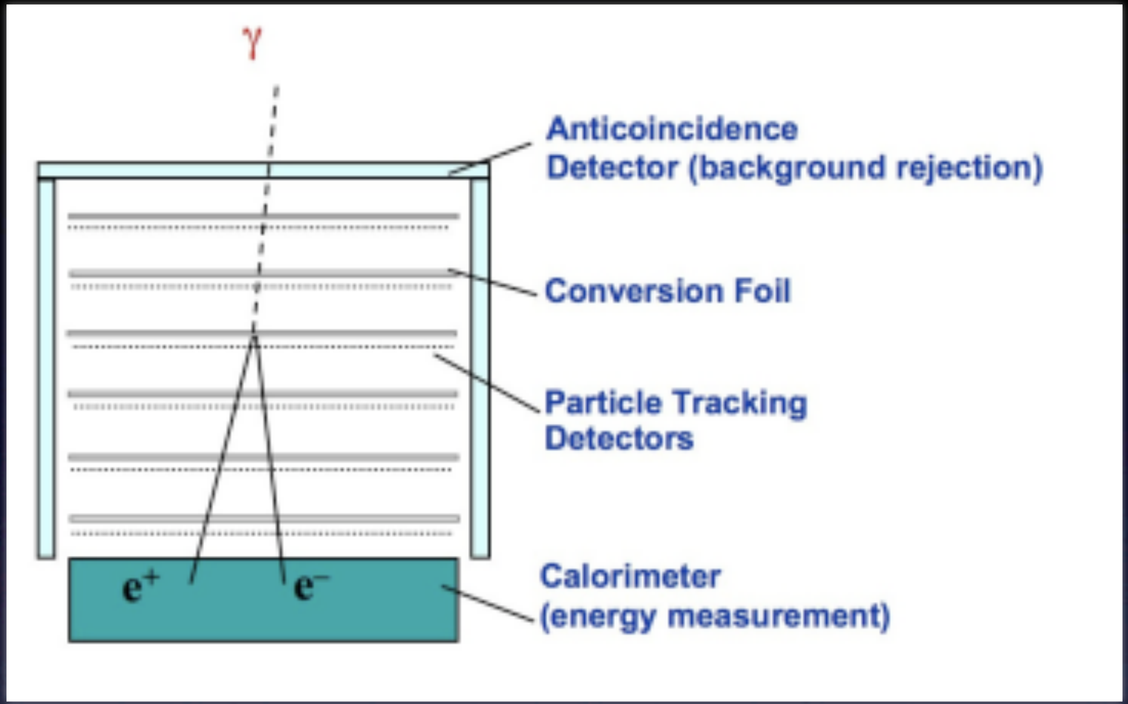
1. the Large Area Telescope : LAT (20 Mev -300 GeV)
2. the Gamma-ray Burst Monitor : GBM (8 keV -40 MeV).





The LAT is an imaging high-energy gamma-ray telescope

Pair-conversion telescope with a precision tracker and calorimeter



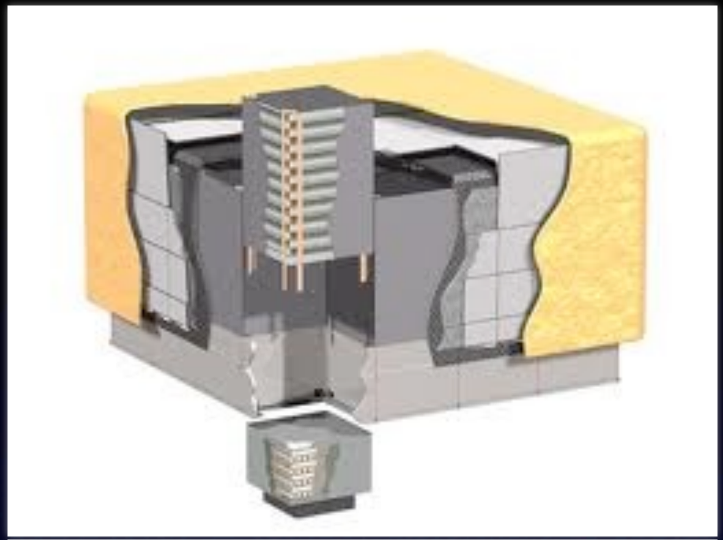
1 photon every 1e6 protons

FOV =2.4 sr ~ 1/5 of the full sky

The LAT scans the entire sky every 3 hours (2 orbits)

95% of observing time is deserved to all-sky survey mode

Some technical notes...



On-axis effective area ≈ 1500 cm^2 @ 100 MeV to ≈ 8000 cm^2 @ E≥1 GeV

Energy resolution better than 10% between ≈ 50 MeV and ≈ 50 GeV.

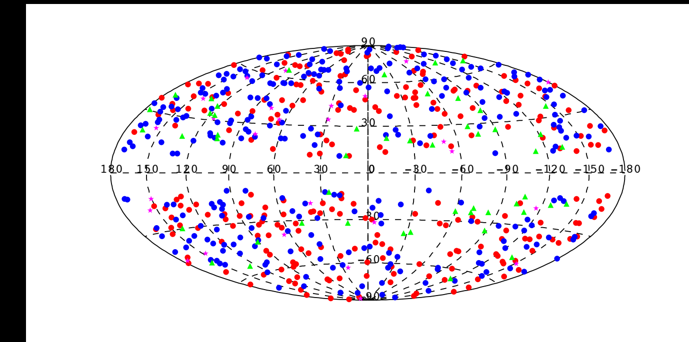
Spatial resolution depends on the photon energy

$R_{68} \approx 3.5^\circ$ at E ≈ 100 MeV

$R_{68} \approx 0.6^\circ$ at E ≈ 1 GeV

1 year (2008 August 4 - 2009 July 4) --> 1 LAC

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



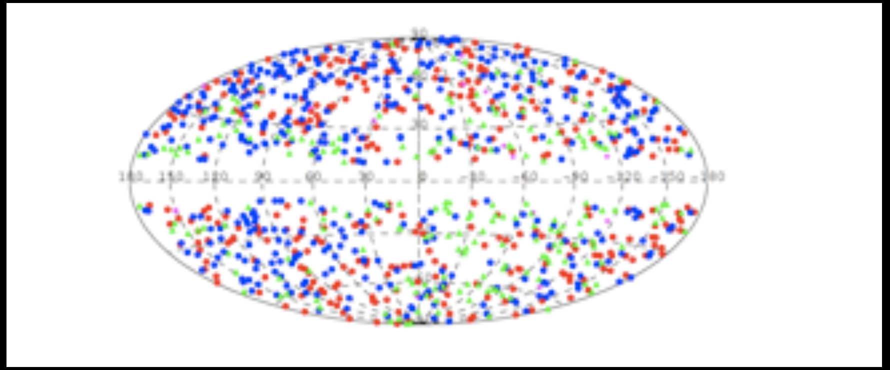
Class	Number in 1LAC (2LAC)	Characteristics	Prominent Members
All	599 (885)		
BL Lac objects	275 (395)	weak emission lines	AO 0235+164
... LSP	64 (61)	$\nu_{pk}^{syn} < 10^{14}$ Hz	BL Lacertae
... ISP	44 (81)	10^{14} Hz $< \nu_{pk}^{syn} < 10^{15}$ Hz	3C 66A, W Comae
... HSP	114 (160)	$\nu_{pk}^{syn} > 10^{15}$ Hz	PKS 2155-304, Mrk 501
FSRQs	248 (310)	strong emission lines	3C 279, 3C 354.3
... LSP	171 (221)		PKS 1510-089
... ISP	1 (3)		
... HSP	1 (0)		
New Classes[1]	26 (24)		
... Starburst	3 (2)	active star formation	M82, NGC 253
... MAGN	7 (8)	steep radio spectrum AGNs	M87, Cen A, NGC 6251
... RL-NLS1s	4 (4)	strong FeII, narrow permitted lines	PMN J0948+0022
... NLRGs	4 (–)[3]	narrow line radio galaxy	4C+15.05
... other sources[2]	9 (11)		
Unknown	50 (156)		

[1]Total adds to 27, because the RL-NLS1 source PMN J0948+0022 is also classified as FSRQ in the 1LAC
[2]Includes PKS 0336-177, BZU J0645+6024, B3 0920+416, CRATES J1203+6031, CRATES J1640+1144, CGRaBS J1647+4950, B2 1722+40, 3C 407, and 4C +04.77 in 1LAC Clean Sample
[3]Class deprecated in 2LAC

Dermer 2012, arXiv1202.2814

2 years (2008 August 4 - 2010 August 1) --> 2 LAC

Ackermann, M., et al. 2011, ApJ, 743, 151 (2LAC);
Nolan, P.L., et al. 2012, ApJS, 199,31 (2FGL)



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~3%

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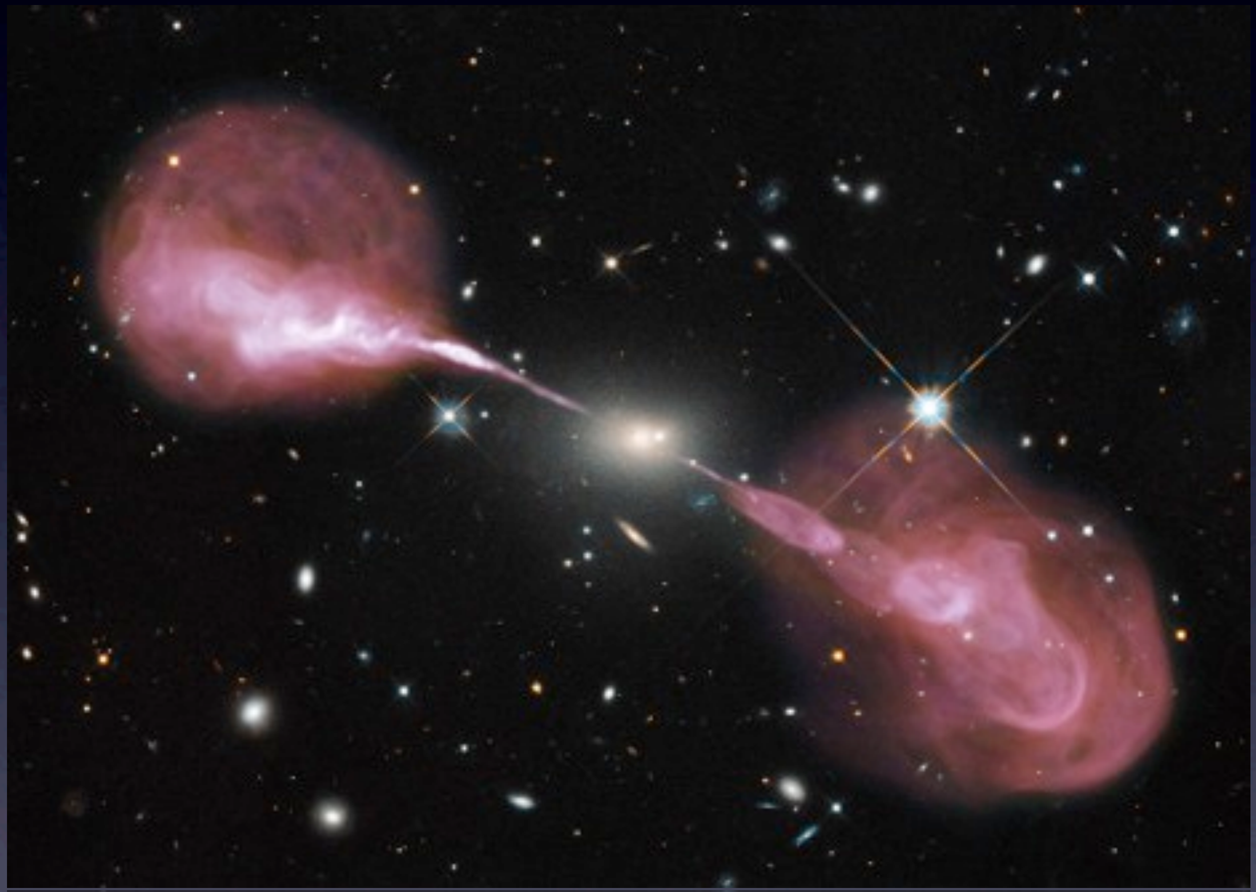
Fermi & Misaligned AGN

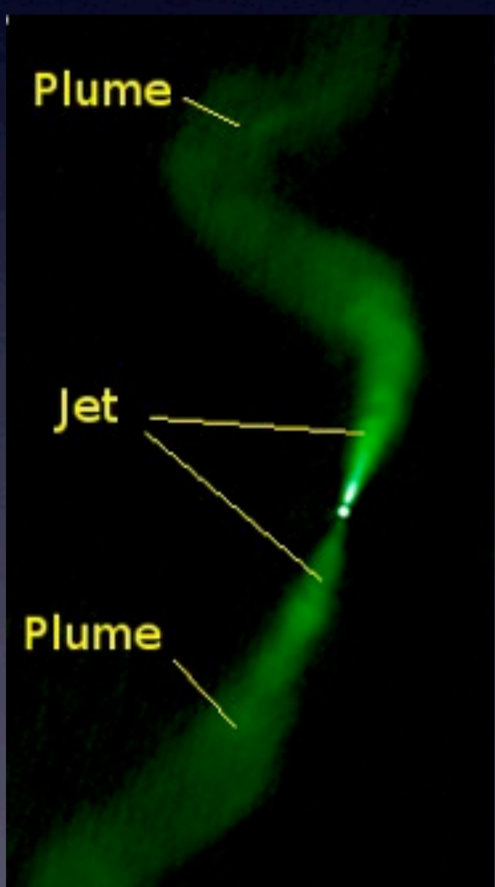


Misaligned AGNs

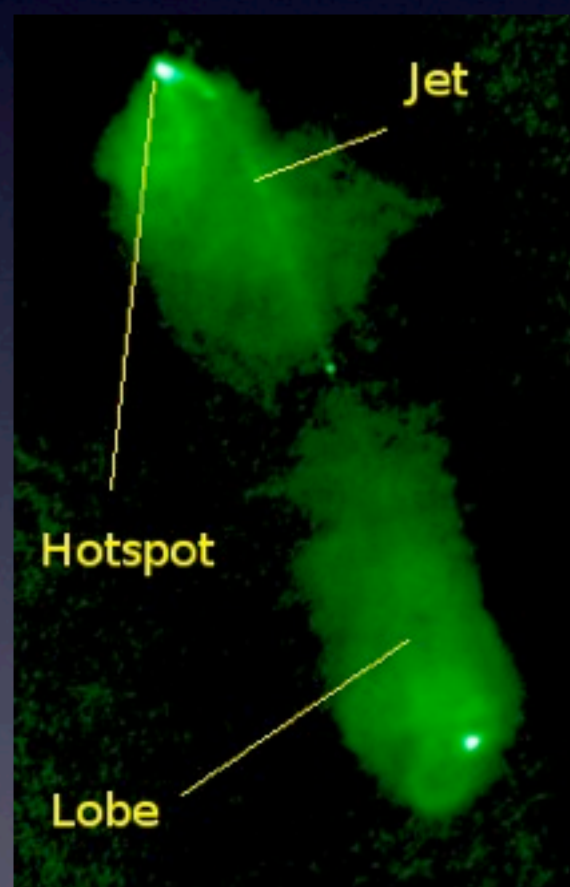
(Radio Galaxies+Steep Spectrum Radio Quasars)

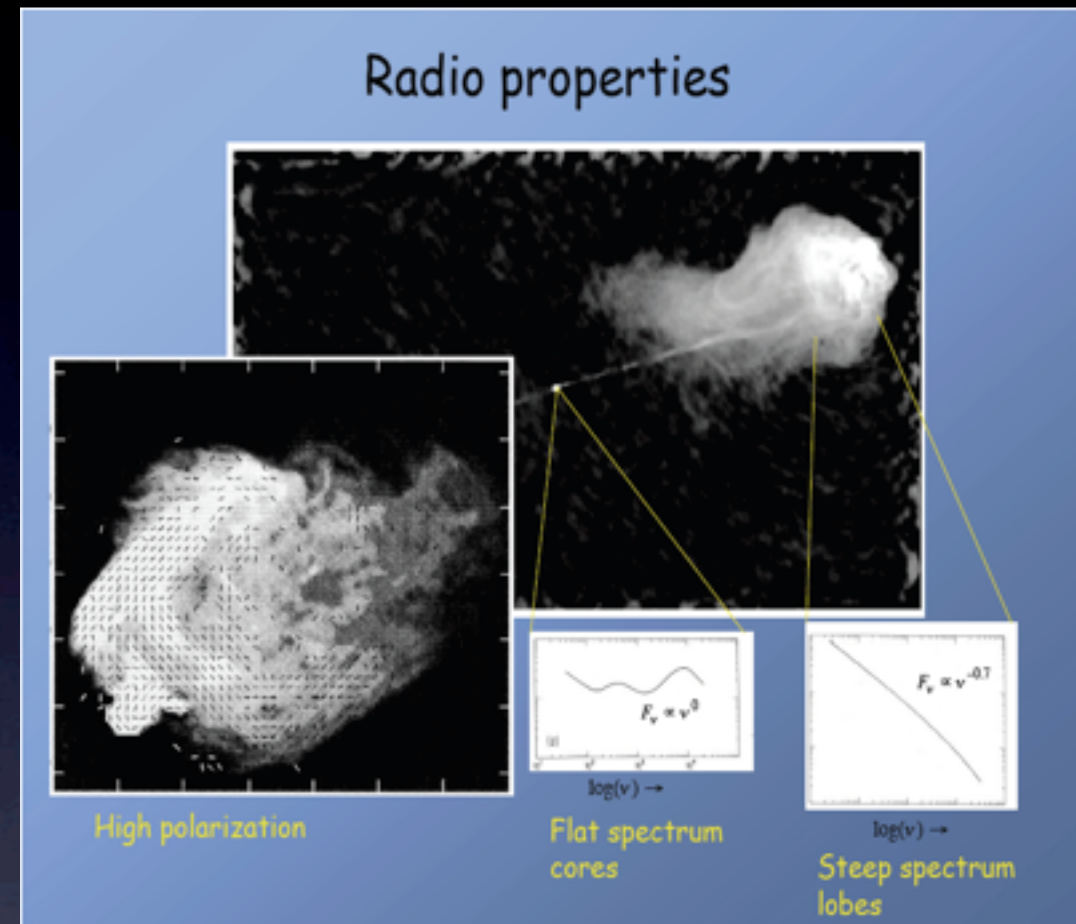
1. Steep radio spectra (α_r>0.5)

FRI/jet dominated



FRII/lobe dominated

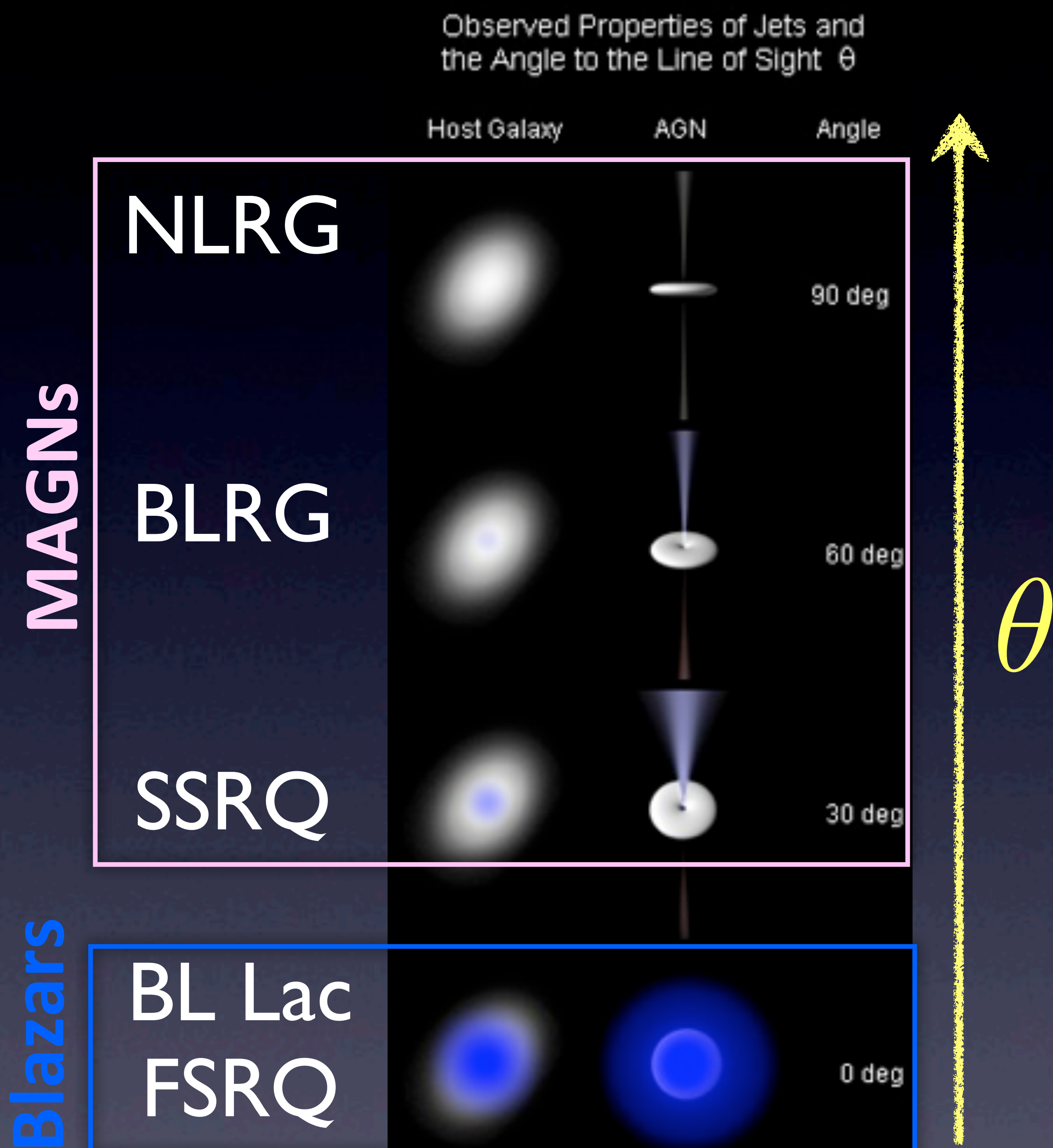




2. Resolved and possibly symmetrical structures in radio maps

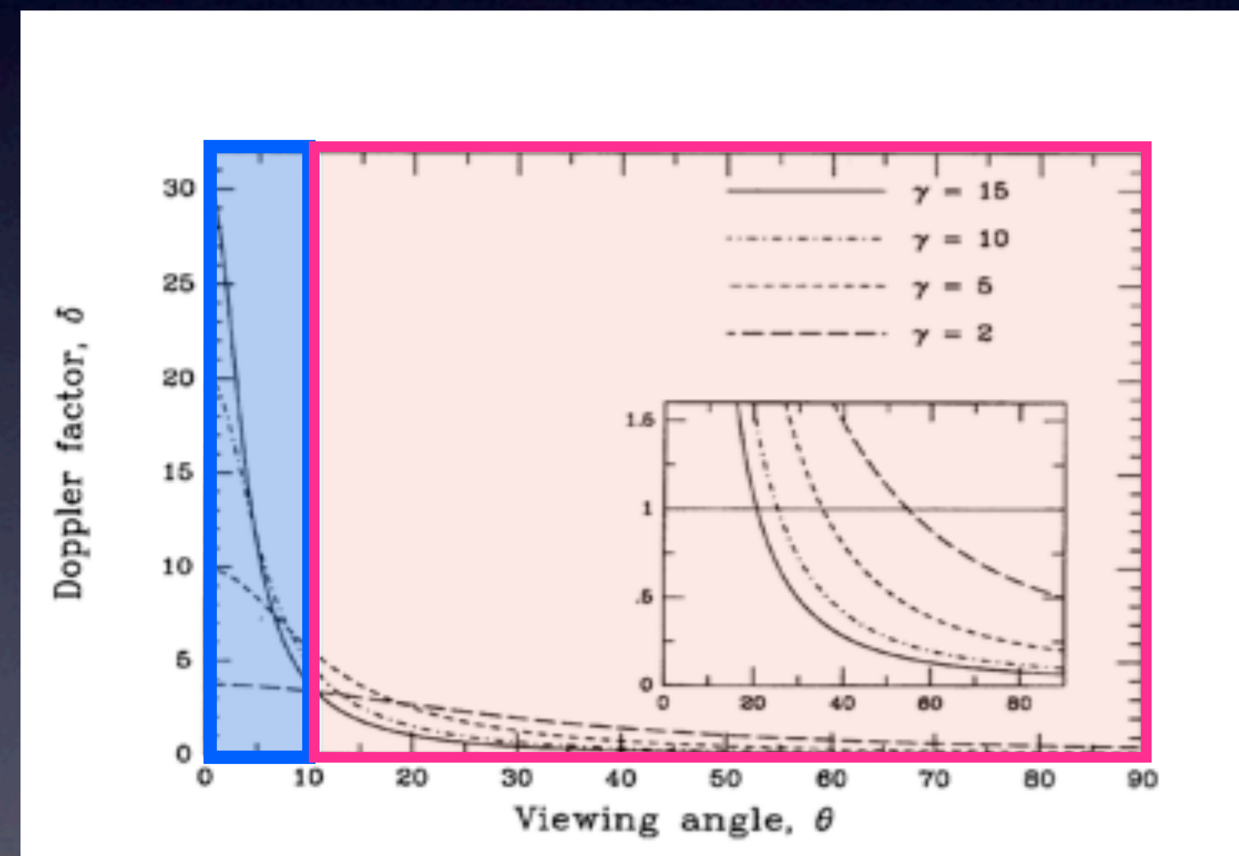
FRIs are considered the PARENT POPULATION of BL LACs
FRIIs are considered the PARENT POPULATION of FSRQs (Urry & Padovani 1995)

MAGNs are Radio Sources with the jet not directly pointed towards the observer

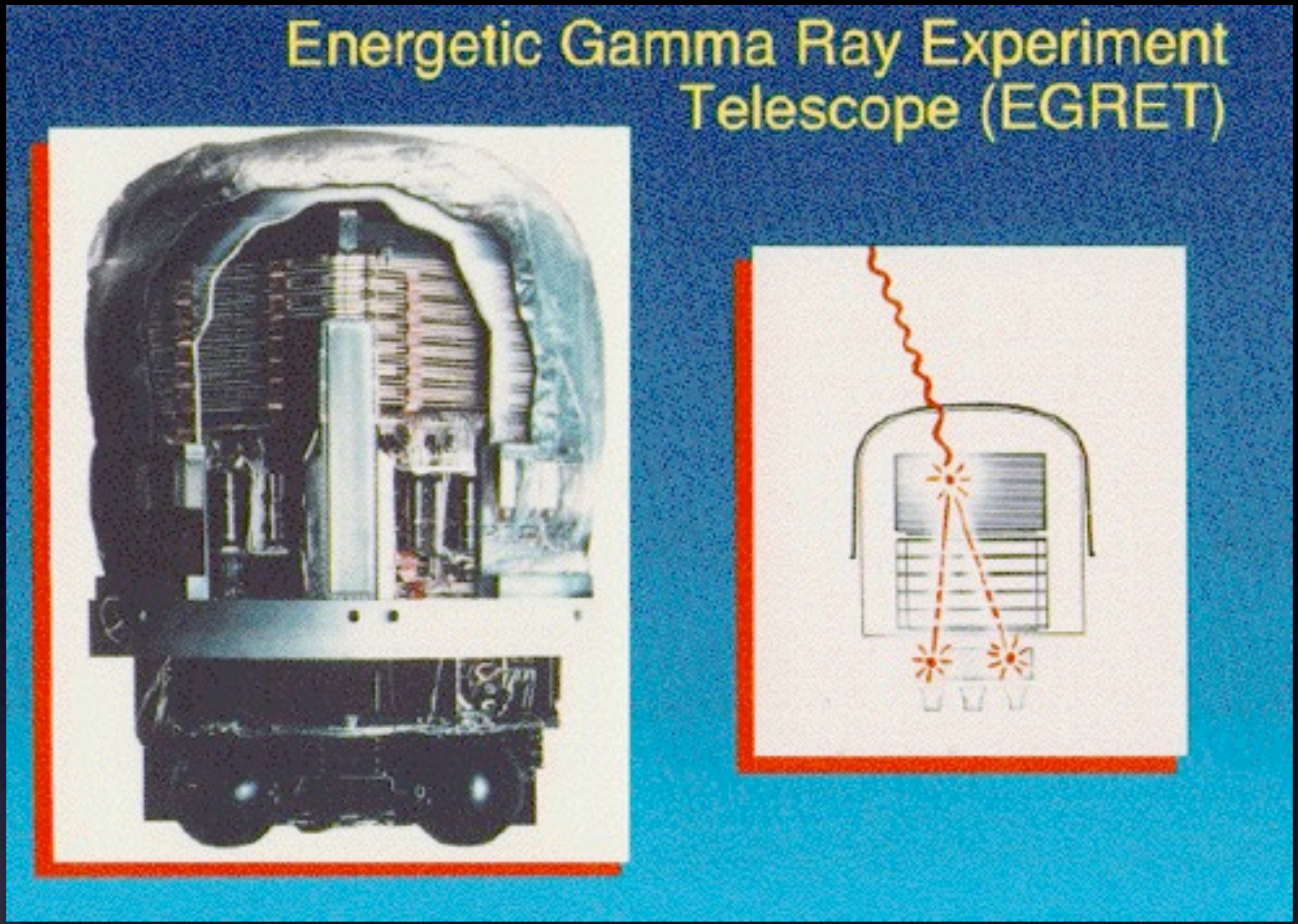


$$\delta = 1/\Gamma(1-\beta \cos\theta)$$

DOPPLER FACTOR: relates the intrinsic and observed flux for a source moving at relavistic speed



EGRET's Legacy

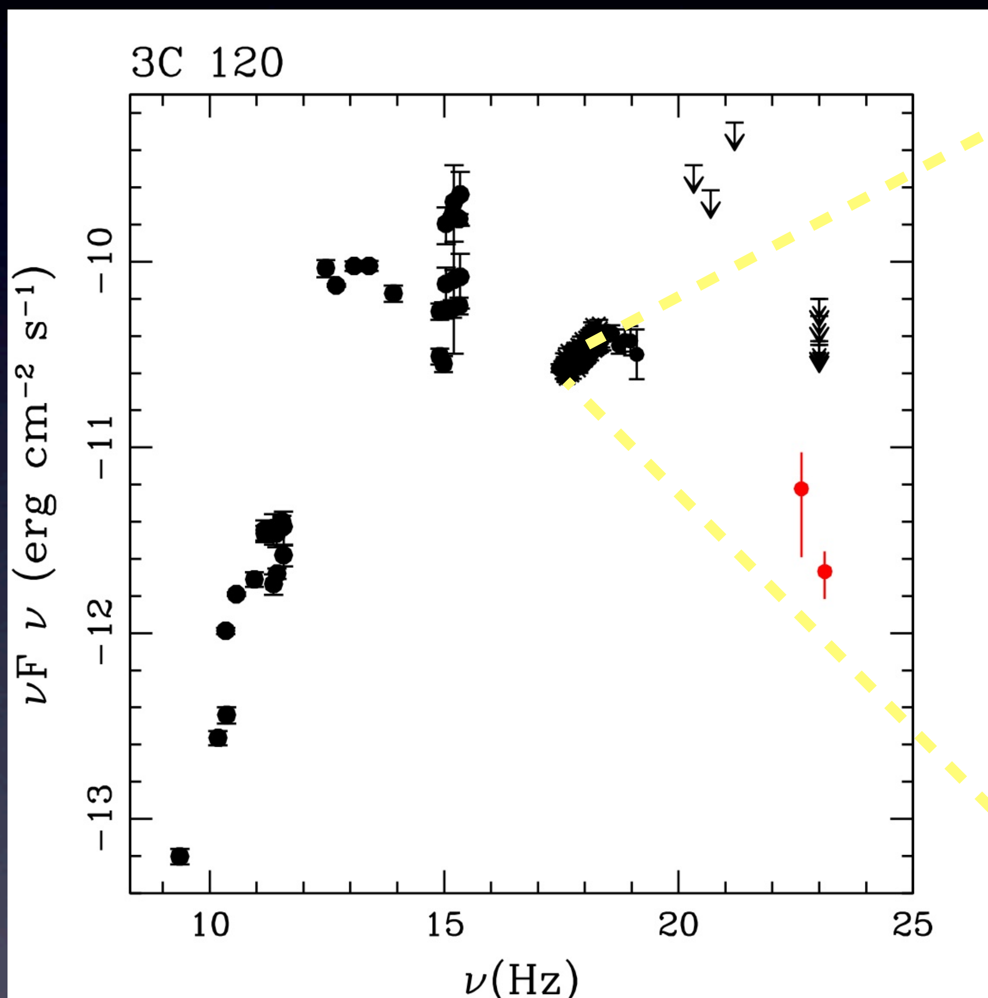


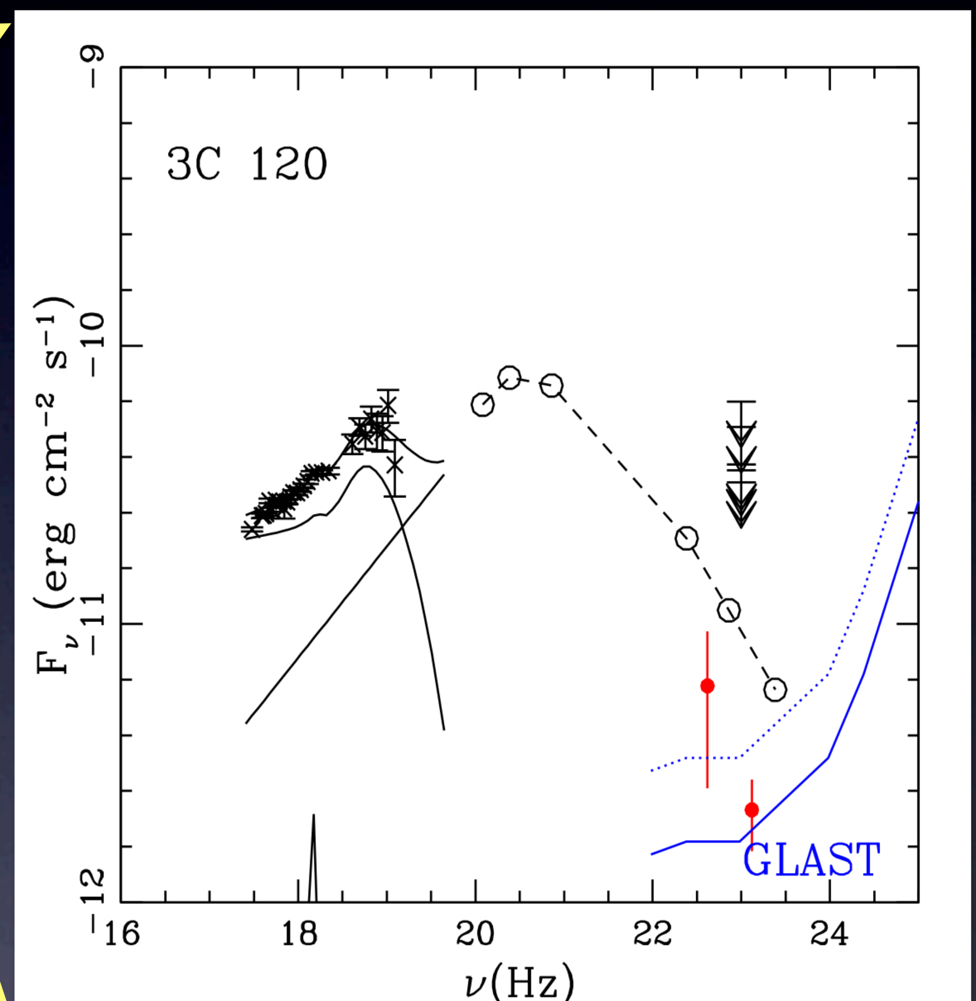
Centaurus A NGC 6251 3C 111

Nolan et al. 1996; Mukherjee et al. 2002; Sguera et al. 2005; Hartmann et al. 2008

However some works already predicted the possible detection of several FRIs and some Broad Line Radio Galaxies by Fermi before its launch

(Stawarz et al. 2003, 2006; Ghisellini et al. 2005; Grandi & Palumbo 2007)





(Grandi & Palumbo 2007)

First sample of MAGNs

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

Search for Steep Spectrum Radio Sources

Cross-correlation of three complete radio catalogs (3CR, 3CRR & MS4) 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 + 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)

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;

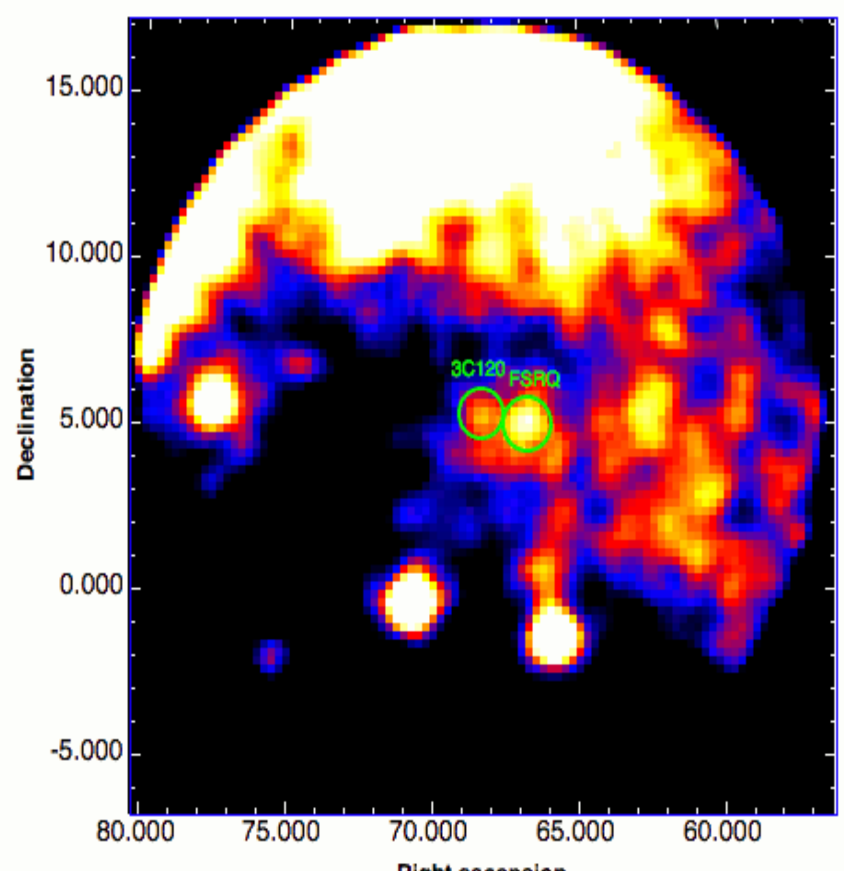
★ These surveys cover most part of the northern and southern sky.

First sample of MAGNs

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

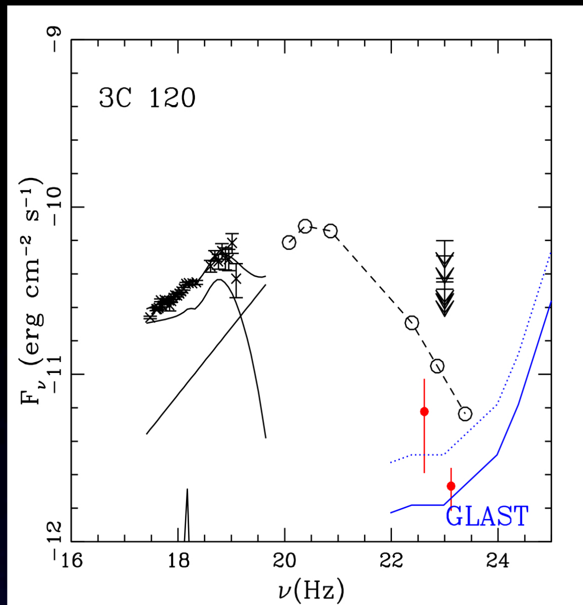
Table 1: The Sample **15-month** (2008 August 4-2009 November 8)

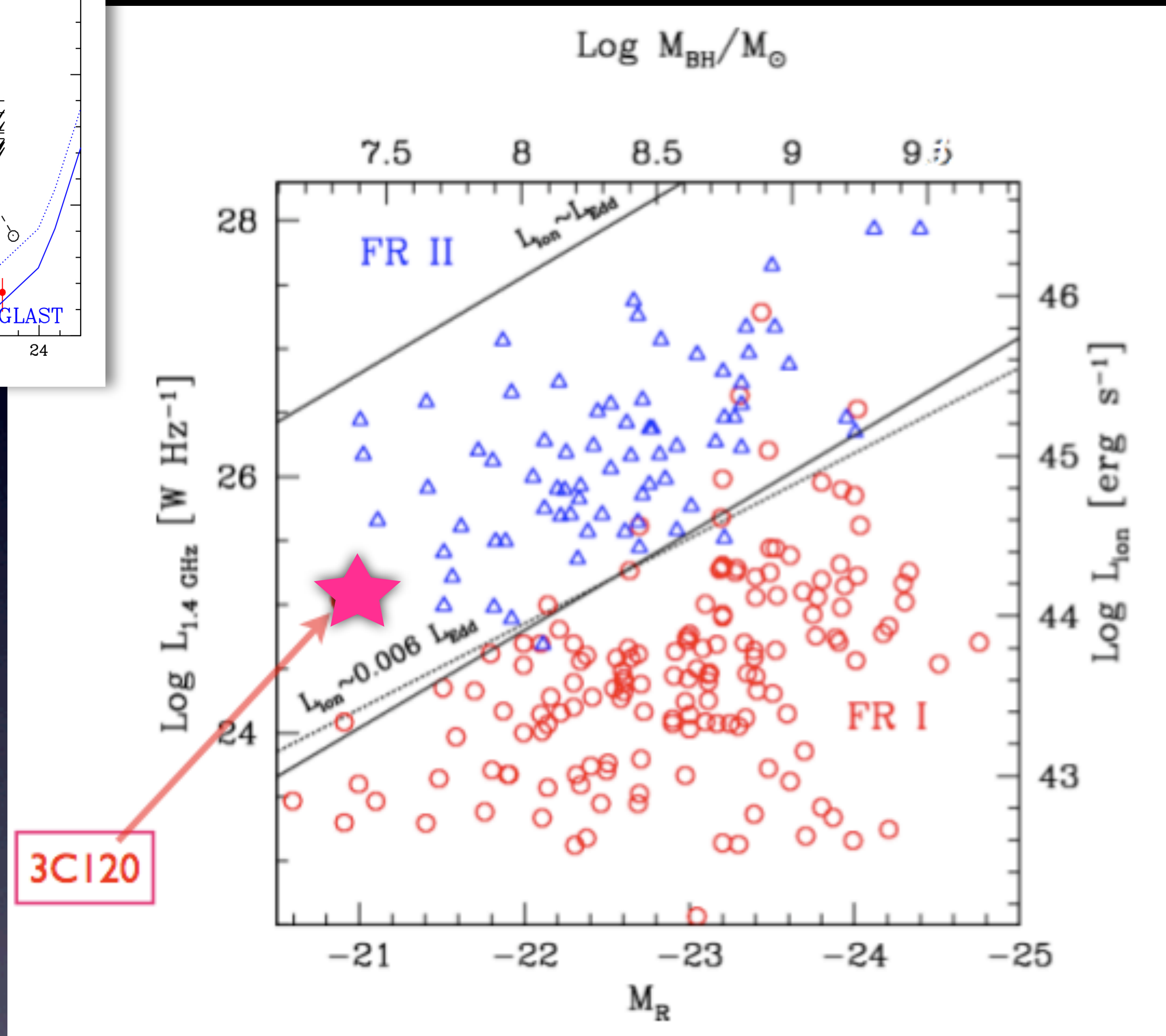
Object	1FGL Name	RA (2000)	Dec (2000)	Redshift	Class Radio	Class Optical	Log (CD) at 5 GHz	ref	Cat.
3C 78/NGC 1218	1FGLJ0308.3+0403	03 08 26.2	+04 06 39	0.029	FRI	G	-0.45	1	3CR
3C 84/NGC 1275	1FGLJ0319.7+4130	03 19 48.1	+41 30 42	0.018	FRI	G	-0.19	2[a]	3CR
3C 111	1FGLJ0419.0+3811	04 18 21.3	+38 01 36	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



Source	TS	Γ	Flux (10^{-8} Phot/sec/cm^2) 0.1-100 GeV	Log Lum (erg/sec) 0.1-10 GeV
3C120	32	2.7 ±0.3	2.9± 1.7	43.43

3C 120 is a FRI with a powerful accretion disk

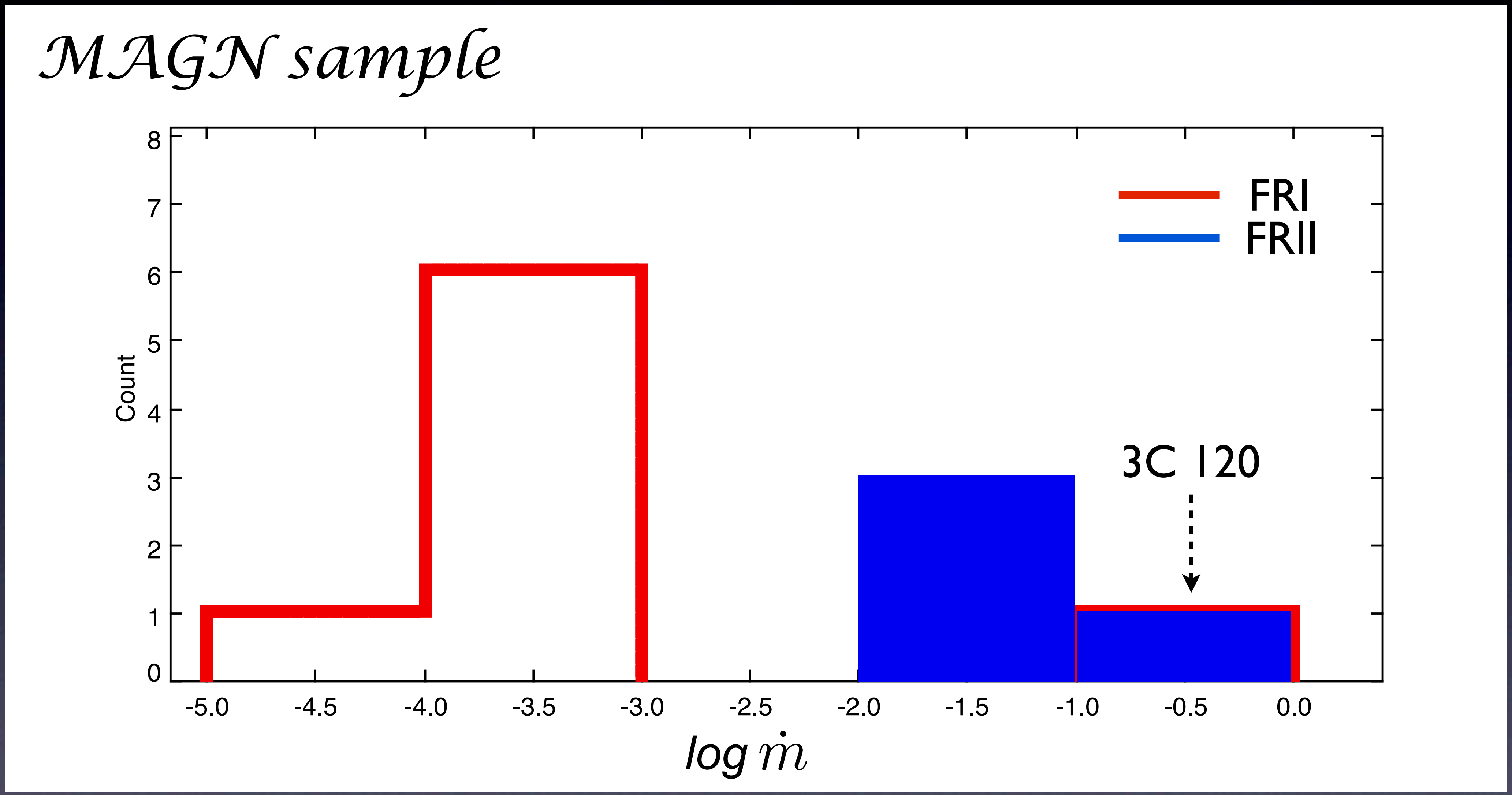




Ghisellini & Celotti 2001

3C 120 is a FRI with a powerful accretion disk

Torresi 2012



$$\dot{m} = \frac{L_{Bol}}{\eta L_{Edd}},\ \eta=1$$

First sample of MAGNs

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

6 FRI - 4 FRII - 3C 120

Object	TS	Γ	Flux[a] (> 100 MeV)	*Log Lum*[b] (100 MeV-10 GeV)
3C 78/NGC 1218	35	1.95±0.14	4.7 ±1.8	42.84 ±0.38
3C 84/NGC 1275	4802	2.13± 0.02	222 ±8	44.00 ±0.04
3C 111	34	2.6 ±0.2	40 ±8[c]	44.00 ±0.27
3C 120	32	2.7±0.3	29 ±0.17	43.43 ±0.58
PKS 0625-354[d]	97	2.1±0.2	5 ±1	43.7±2.5
3C 207	79	2.5 ±0.1	23.7 ±3.9	46.44 ±0.16
PKS 0943-76	65	2.83 ± 0.16	55 ±12	45.71±0.22
M87/3C 274	194	2.21 ± 0.14	23.9 ± 6.2	41.67±0.26
CENA	1010	2.75± 0.04	214 ±12	41.13±0.06
NGC 6251	143	2.52 ±0.12	36 ±8	43.30± 0.22
3C 380	95	2.5 ±0.3	31 ±18	46.57± 0.59

[a] - $\times 10^{-9}$ Phot cm^{-2} s^{-1}

[b] - erg s^{-1}

[c] - Flux was estimated keeping the spectral slope fixed

[d] - Likelihood analysis limited to the 300 MeV-100 GeV. Flux (> 300 MeV); Lum extrapolated down to 100 MeV

MAGNs are generally <u>faint</u> and <u>soft</u> sources in the GeV band:

$F(>0.1\ GeV) \sim 10^{-8}$ phot $cm^{-2}\ s^{-1}$

$\Gamma \geq 2.4$

15-month

3C 78/NGC 1218

3C 84/NGC1275

3C 111

3C 120

PKS 0625-354

3C 207

PKS 0943-76

M87

Cen A

NGC 6251

3C 380

24-month

24-month

3C 84/NGC1275

PKS 0625-354

3C 207

PKS 0943-76

M87

Cen A

NGC 6251

3C 380

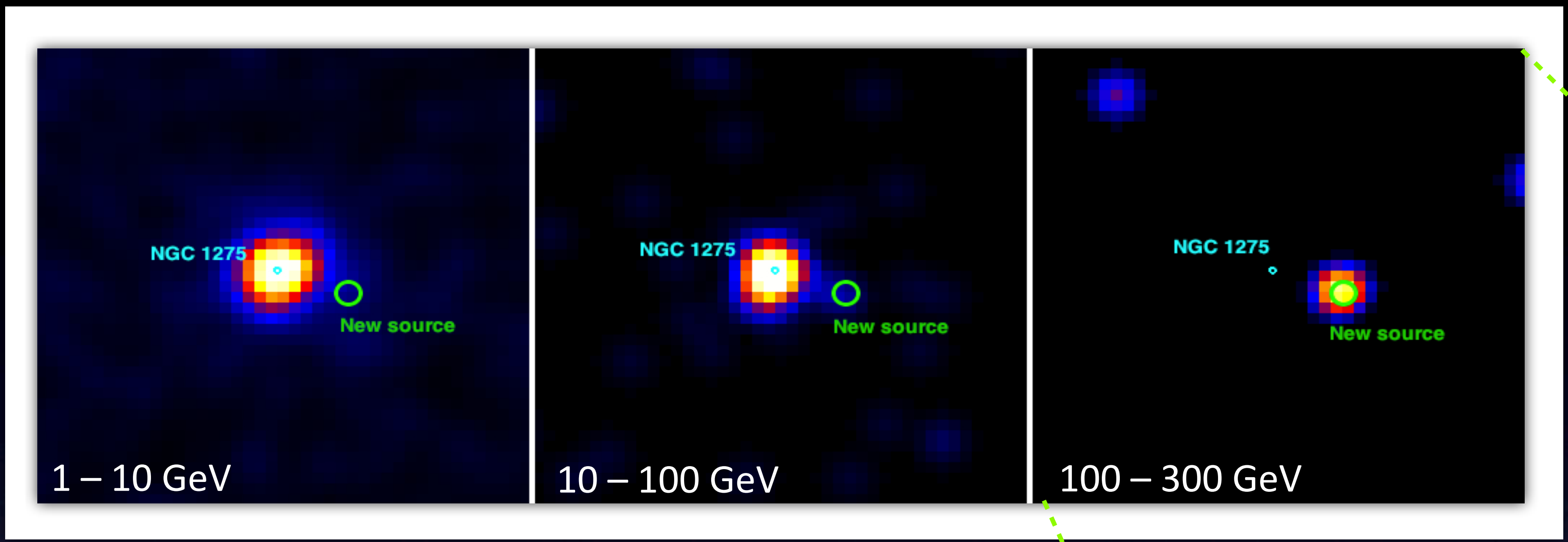
Fornax A

Centaurus B

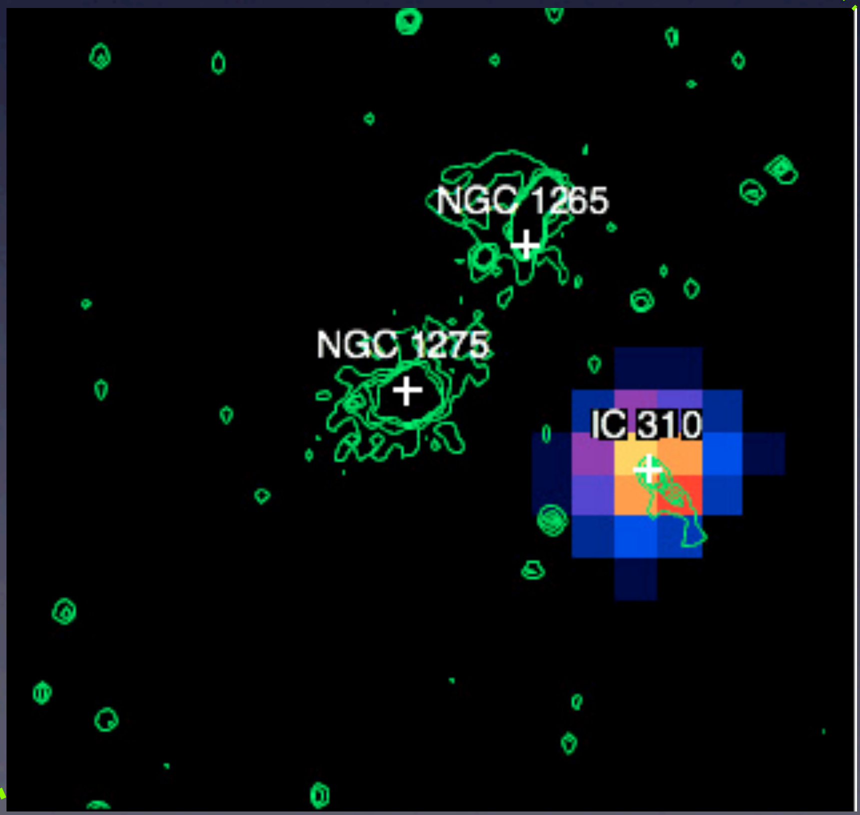
IC 310

Pictor A?

IC 310



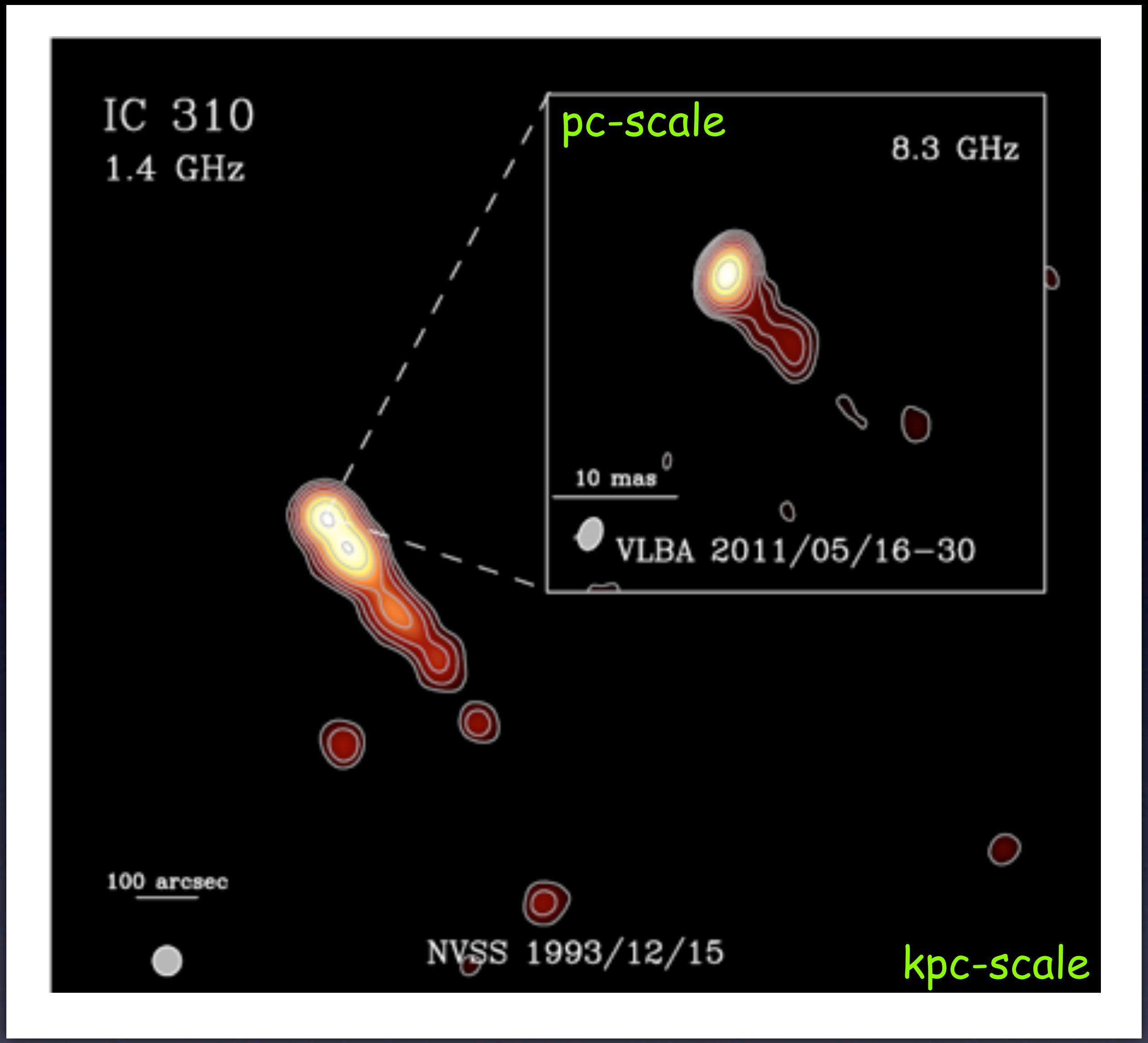
Neronov et al., 2010, A&A, 519, L6
Atel#2510, M. Mariotti, 25 Mar 2010



Radio- WENNS sky survey

IC 310: blazar-like radio structure

stability of jet orientation from pc to kpc scale



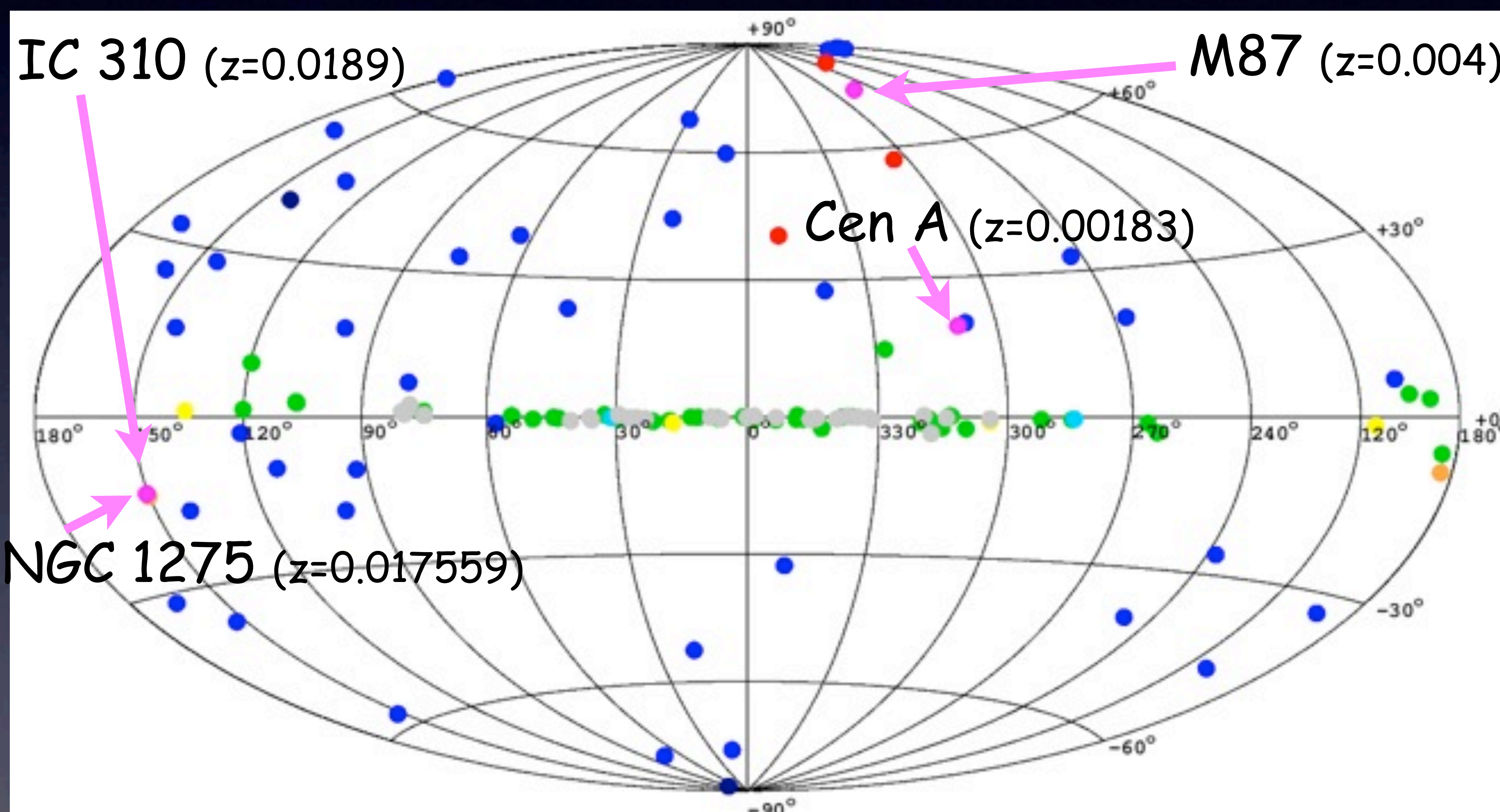
Kadler et al. 2012, A&A, 538, L1

➡ No evidence of interactions of the kpc jet with the ICM --> IC 310 should not be classified as an head-tail radio galaxy

➡ IC 310 seems to represent a low luminosity FRI radio galaxy at a borderline angle (θ<38 deg)

➡ The high-energy emission likely originates in the blazar-like central engine

Several MAGNs emit in the TeV band

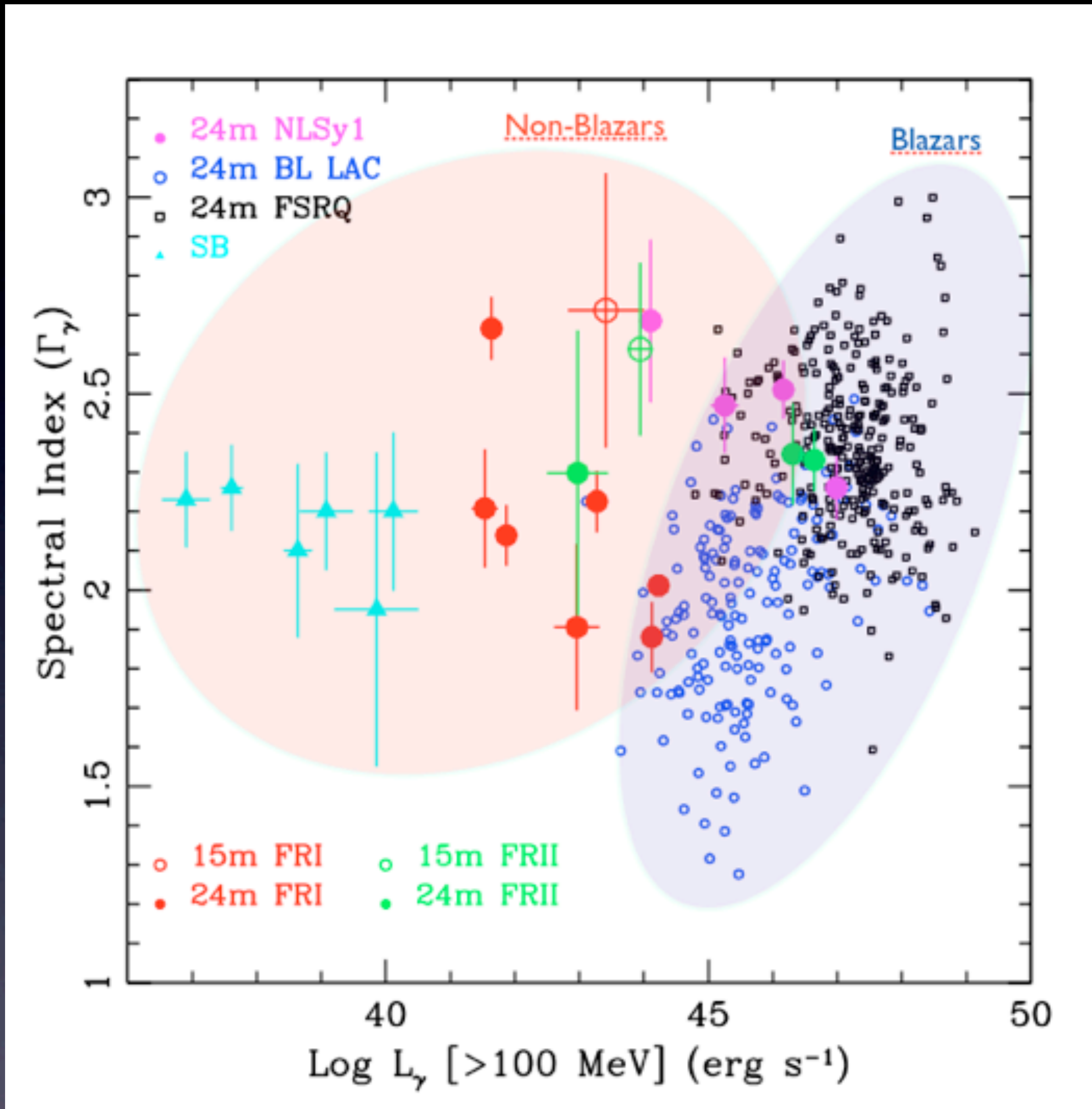


http://www.asdc.asi.it/tgevcat/

http://tevcat.uchicago.edu/

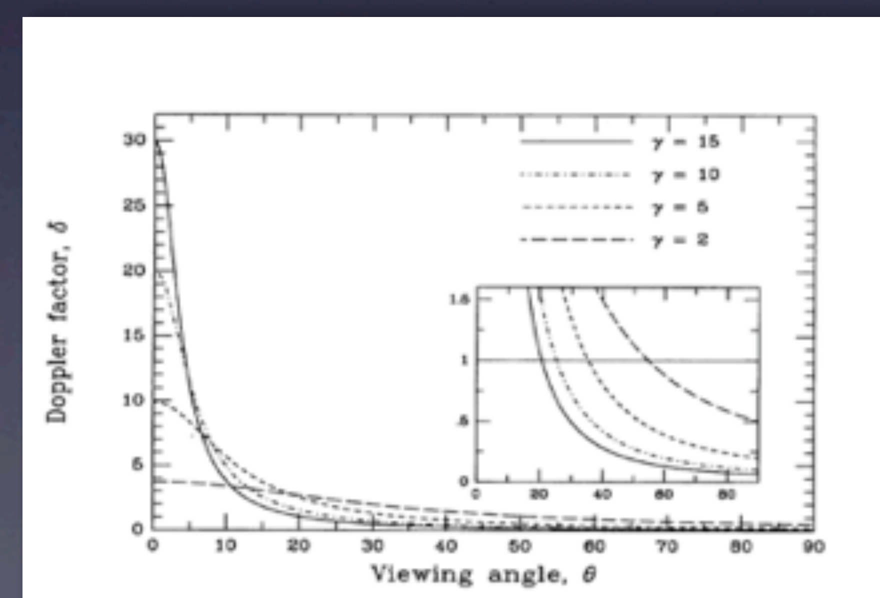
24-month GeV extragalactic sky

Grandi & Torresi 2012

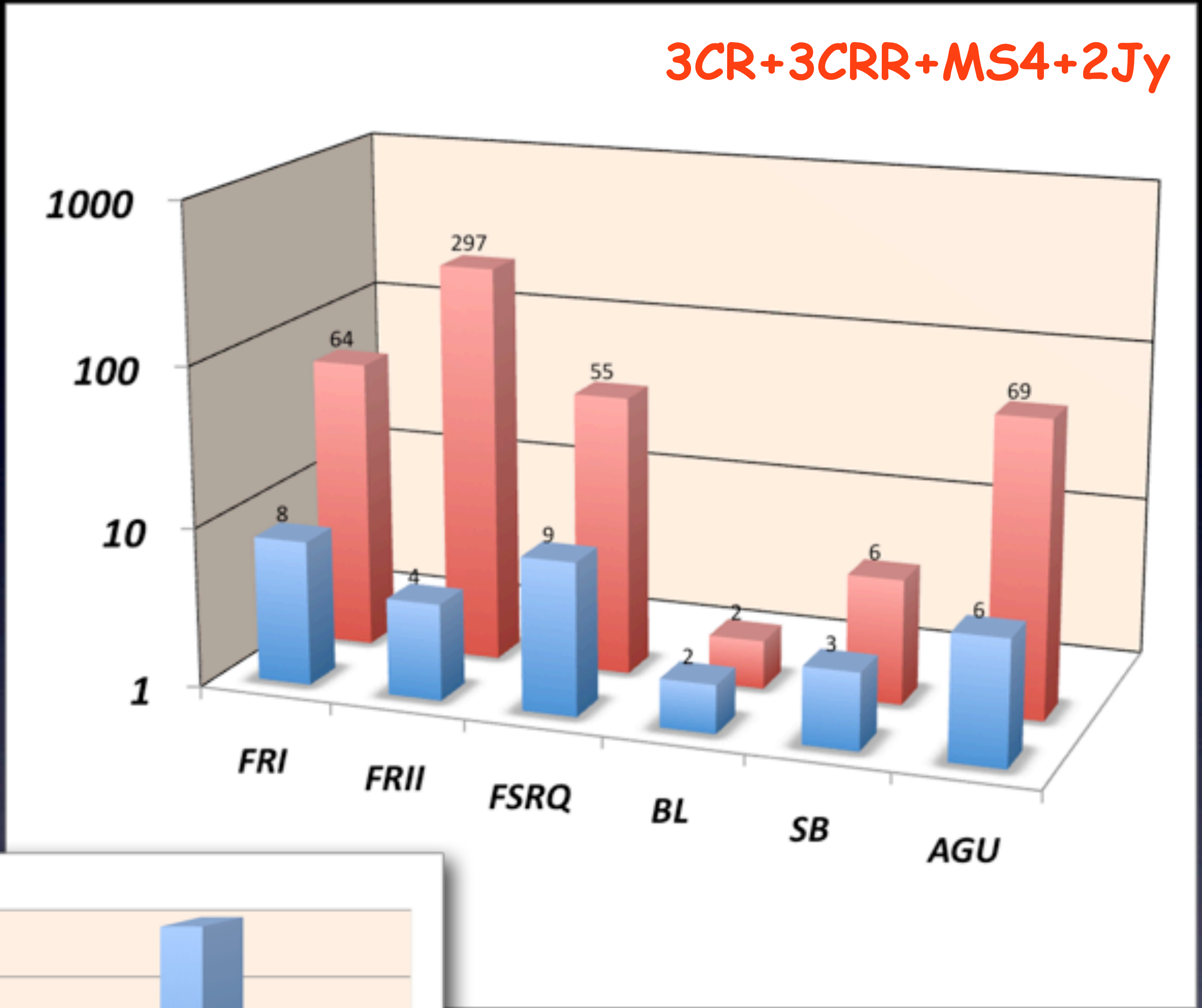


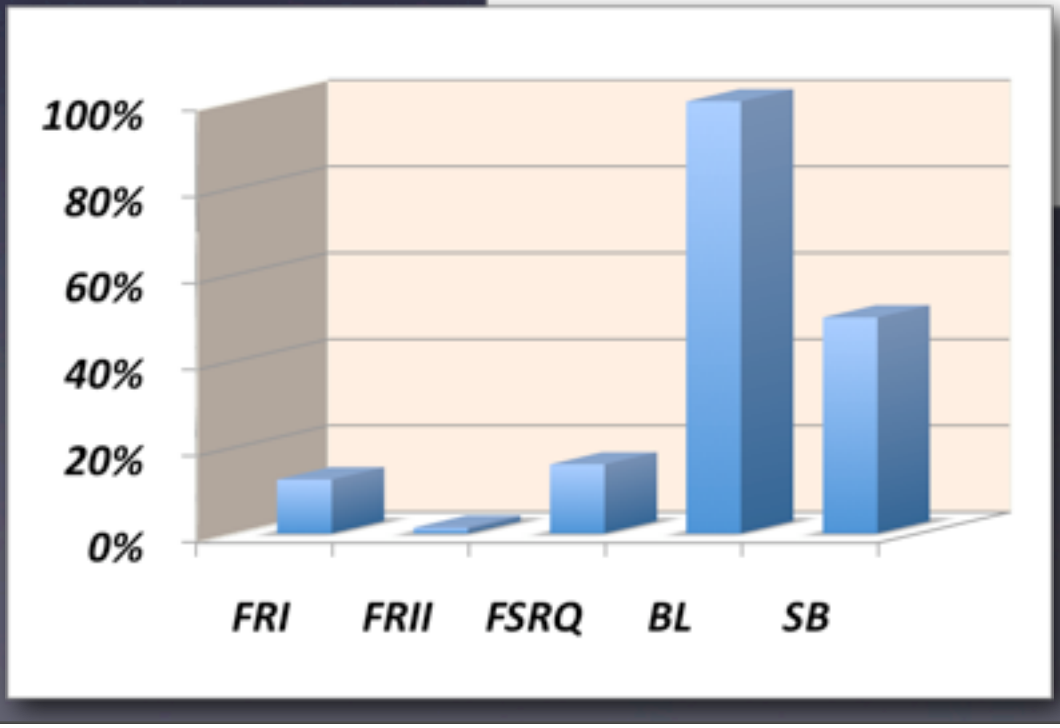
Misaligned AGNs generally occupy a separate region in the Lγ-Γ plane.

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



FRIIs are elusive objects



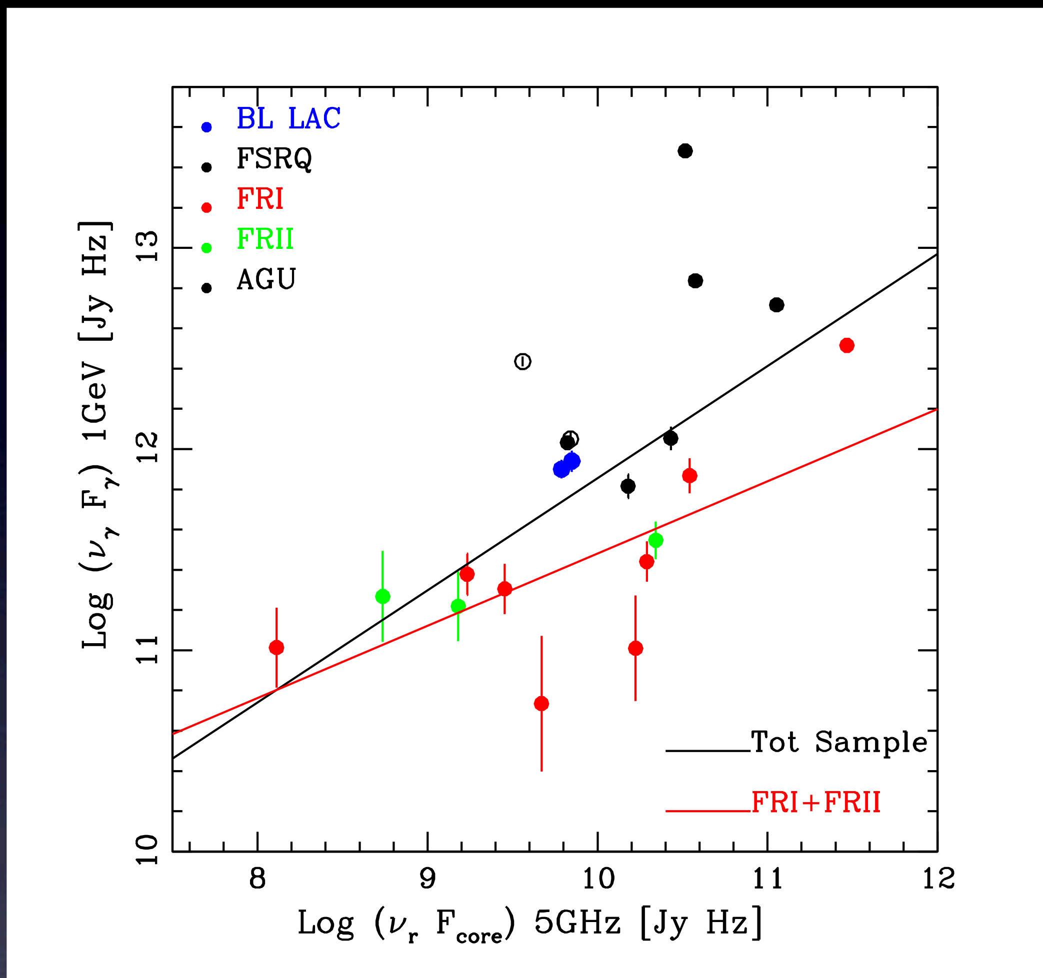


Grandi 2011

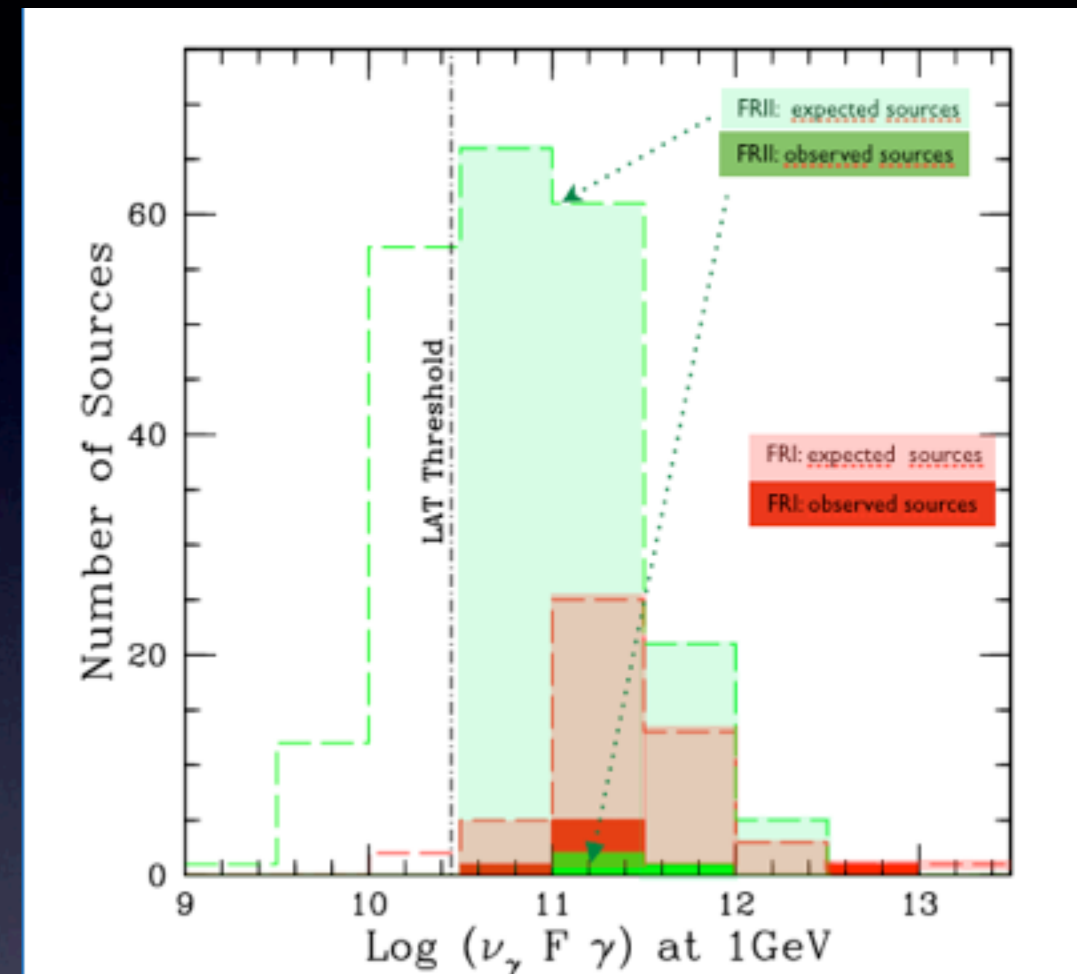
FRIIs are rare, with only 1% of them observed in the γ-ray sky

$$\underbrace{\mathrm{Log}\,(f\,n)_{1GeV}}_{\text{Predicted}} = a + b \times \underbrace{\mathrm{Log}(f\,n)_{5GHz}}_{\text{Observed}}$$

Grandi 2011



Sample	a	b	r	P_r
Total	6.2(1.6)	0.6 (0.2)	0.65	< 0.01
MAGNs	7.9(1.2)	0.4 (0.1)	0.66	< 0.03

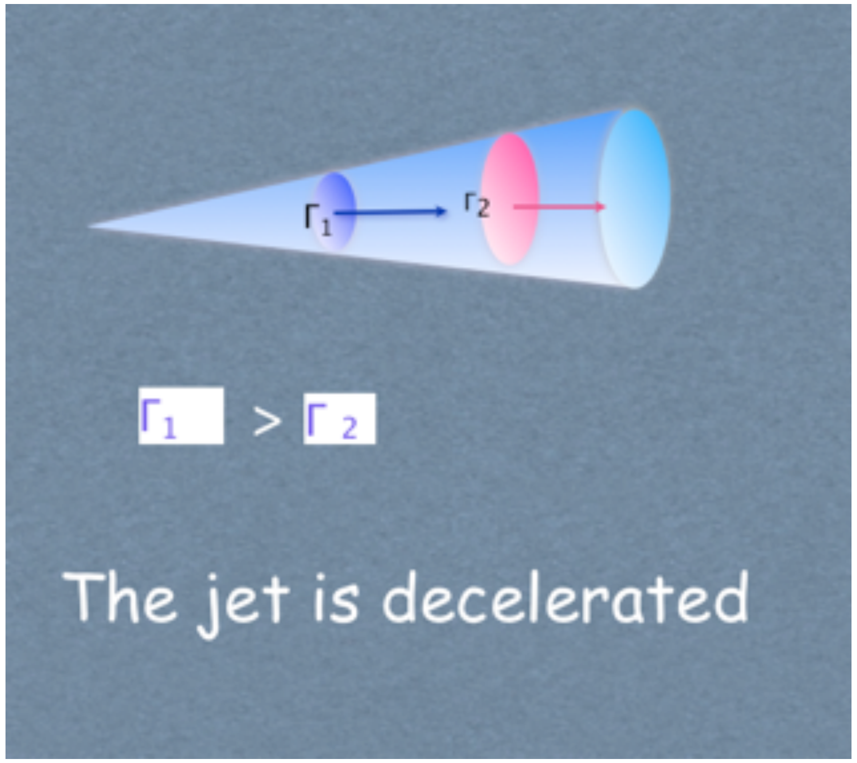


Non-blazar radio sources could be preferentially detected during periods of strong jet activity

The rarity of high power radio sources with GeV emission supports the idea of **structured jets -> different regions at different velocities**

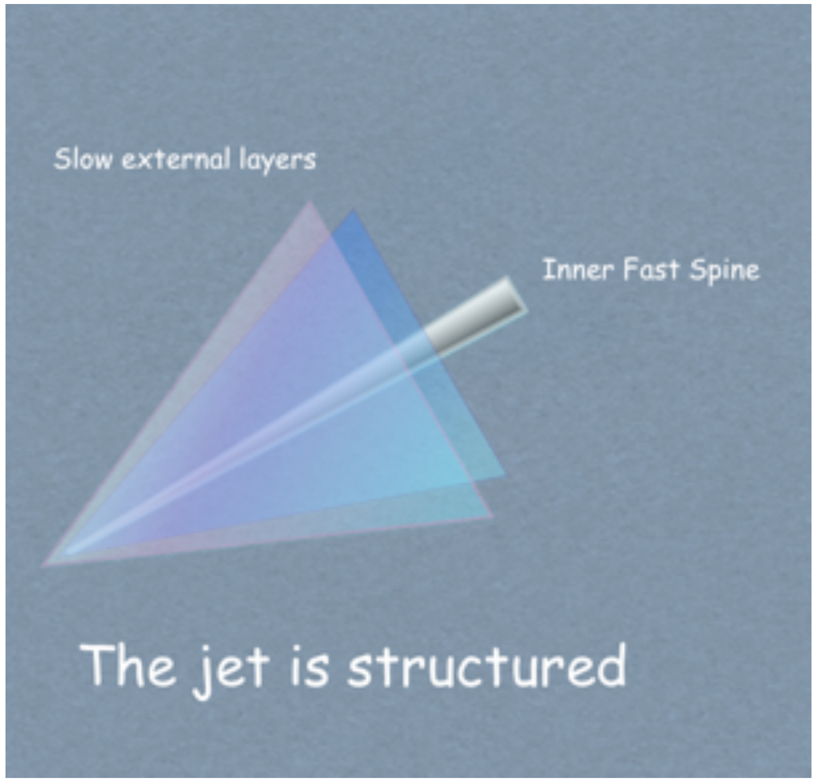
DECELERATING JET

(Georganopoulos & Kazanas 2003)



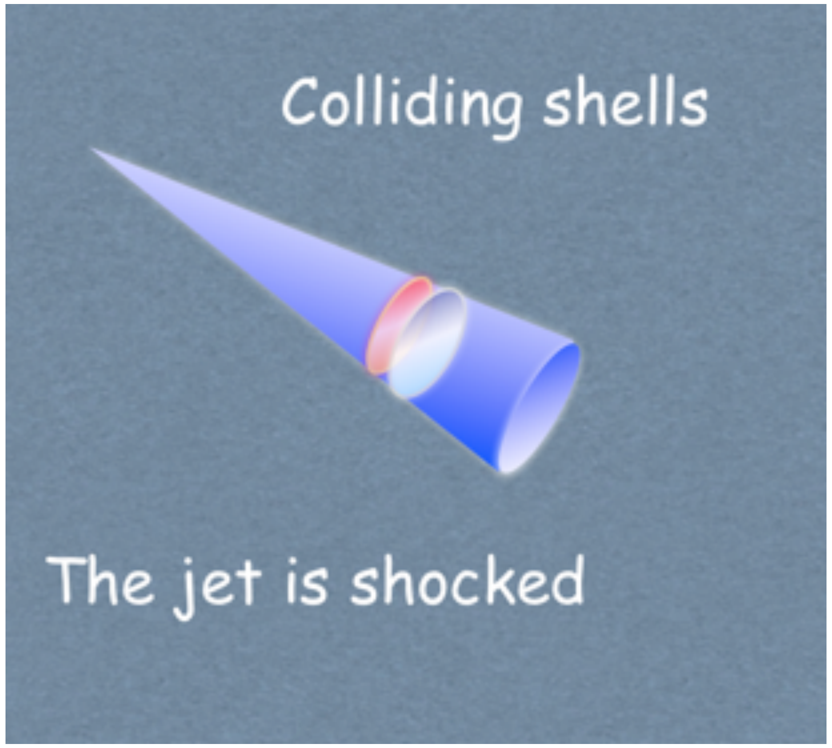
STRUCTURED JET

(Ghisellini, Tavecchio & Chiaberge 05)



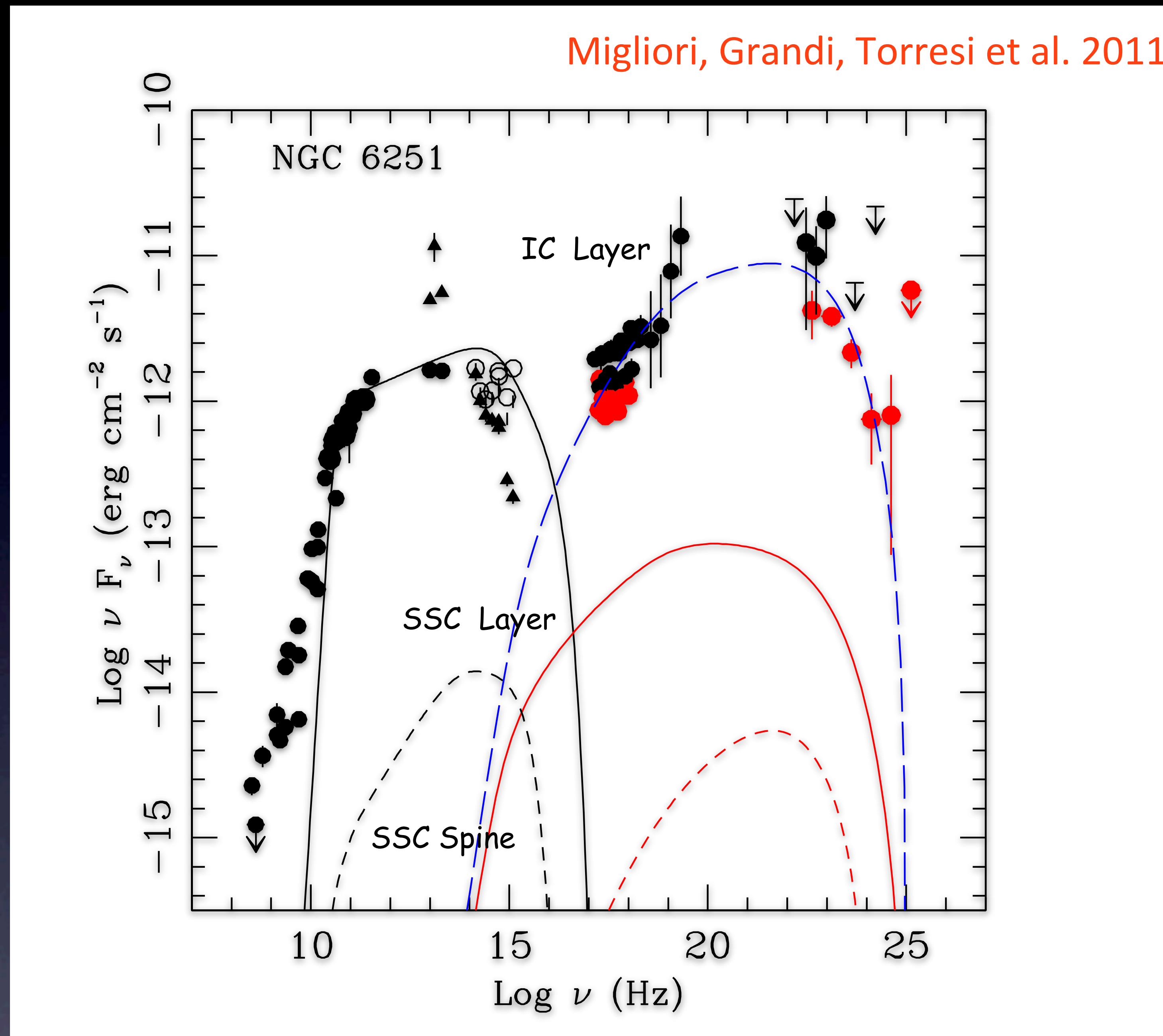
COLLIDING SHELLS

(Böttcher & Dermer 2010)



FRIIs could have less prominent external layers and/or could experience less efficient decelaration processes (see Grandi & Torresi 2011)

SEDs of FRI Radio Galaxies -> one-zone SSC inadequate



Structured Jet

$\theta = 25°$

$\Gamma_{Layer} = 2.4$

$\Gamma_{Spine} = 15$

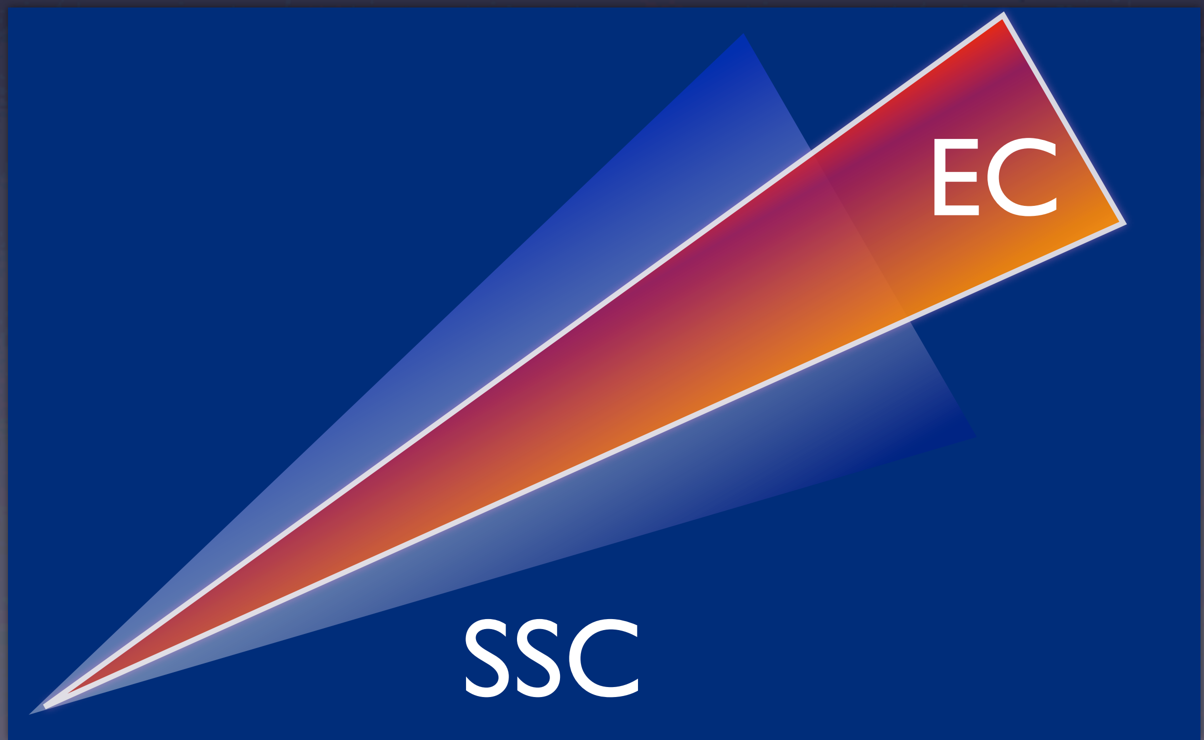
- The hypothesis of homogeneity is relaxed and more regions at different velocities are assumed;
- There is an efficient (radiative) feedback between different regions in the jet that increases the IC emission.

Another possibility could be **different boosting factors in FRIs and FRIIs**

In FRIs inefficient accretion and paucity of environment photons make the Synchrotron Self Compton (SSC) the most important process for the production of gamma-rays $F(\nu)=\delta^{3+\alpha}F'(\nu)$;

In FRIIs the jet propagates through a photon rich environment => External Compton (EC) dominant mechanism $F(\nu)=\delta^{4+2\alpha}F'(\nu)$;

In EC emission the Doppler boosting is stronger and the beaming cone narrower than the SSC radiation
(Dermer 1995, ApJ, 446, L63)



Localization of the gamma-ray emitting region

Two possible scenarios:

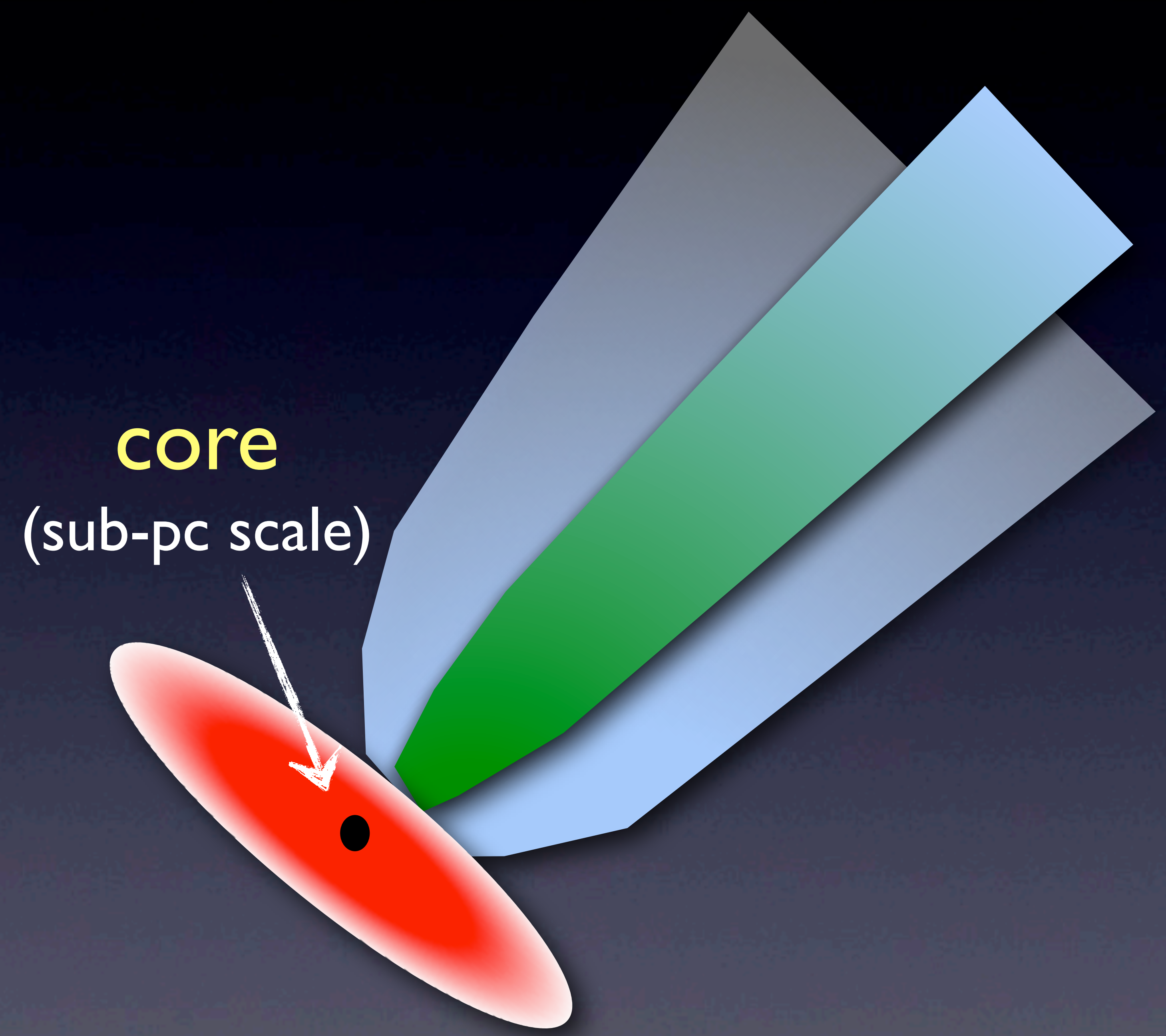
“Near site” scenario

Gamma-ray flares could take place on sub-pc scales, within the BLR (Tavecchio + 2010)

”Far site” scenario

Gamma-ray flares could take place at several parsecs far from the black hole (Marscher +08,09; Jorstad+ 10; Agudo+ 11ab)

The location of the gamma-ray emitting region is not unique



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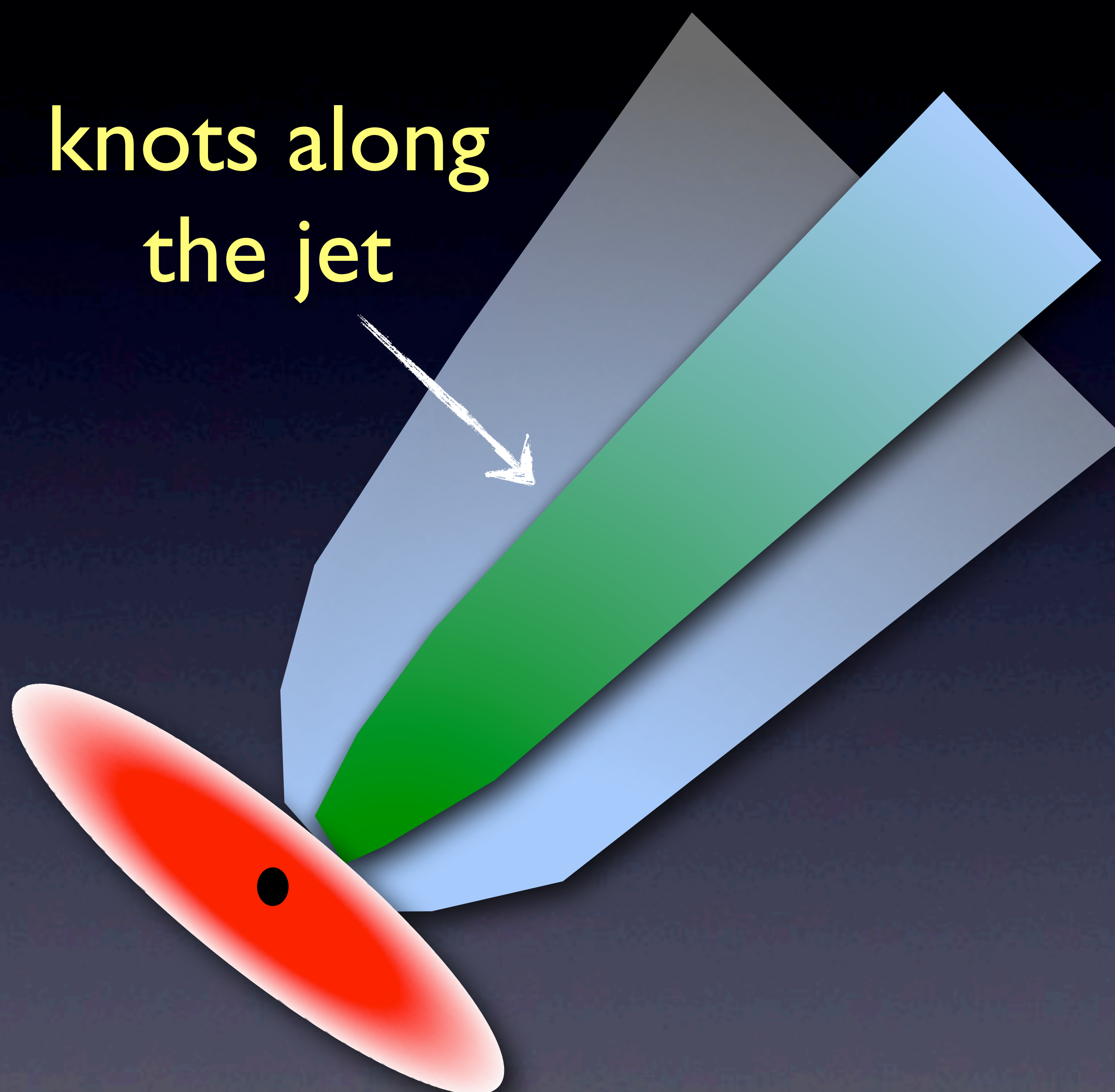
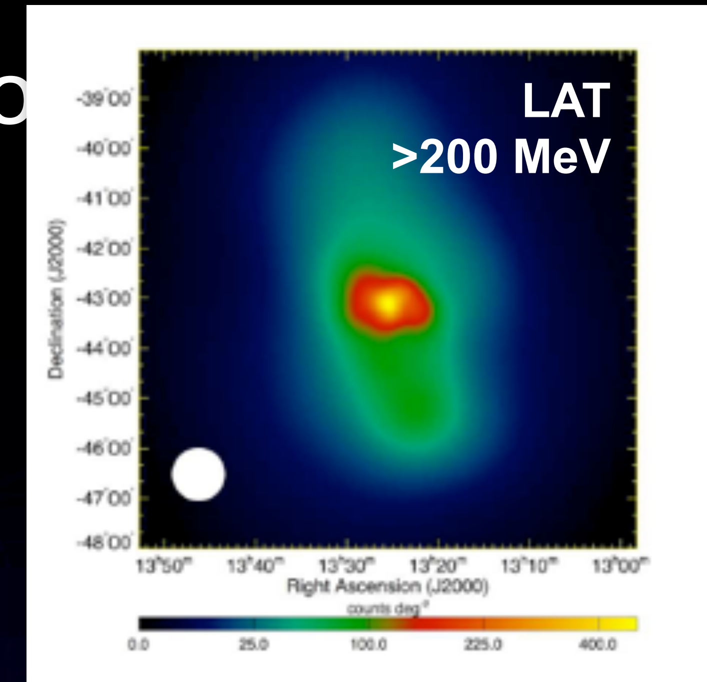


The location of the gamma-ray emitting regio

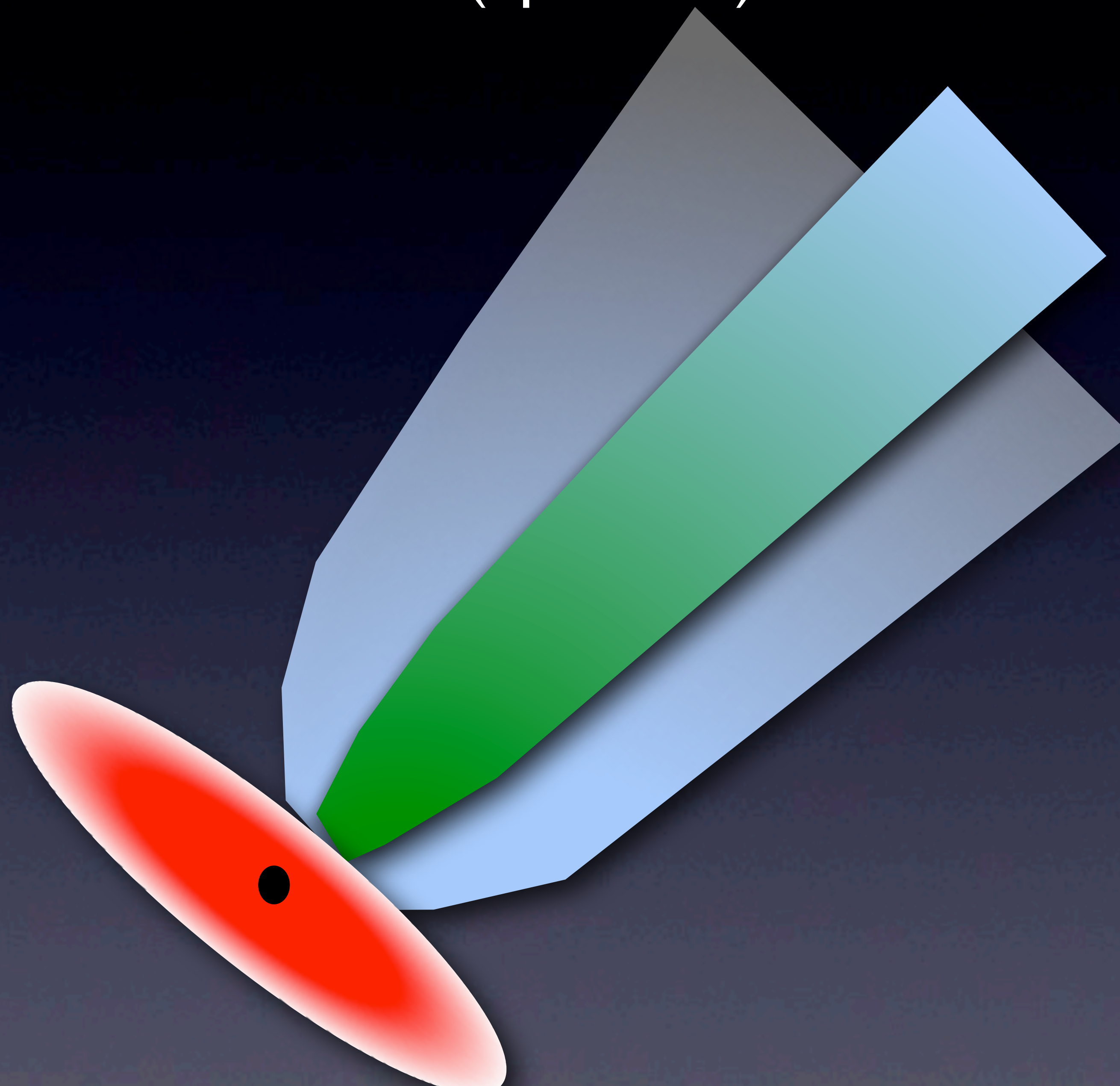
lobes

(kpc scale)



Cen A lobes

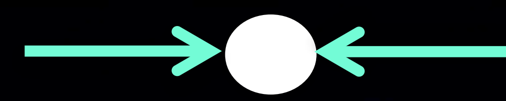
Abdo et al. 2010, Science, 328, 725



Gamma-ray (or monochromatic) variability studies alone can provide information on the **size** of the emitting region

$$R \leq \Delta t c \delta / (1+z)$$

but not on its localization...



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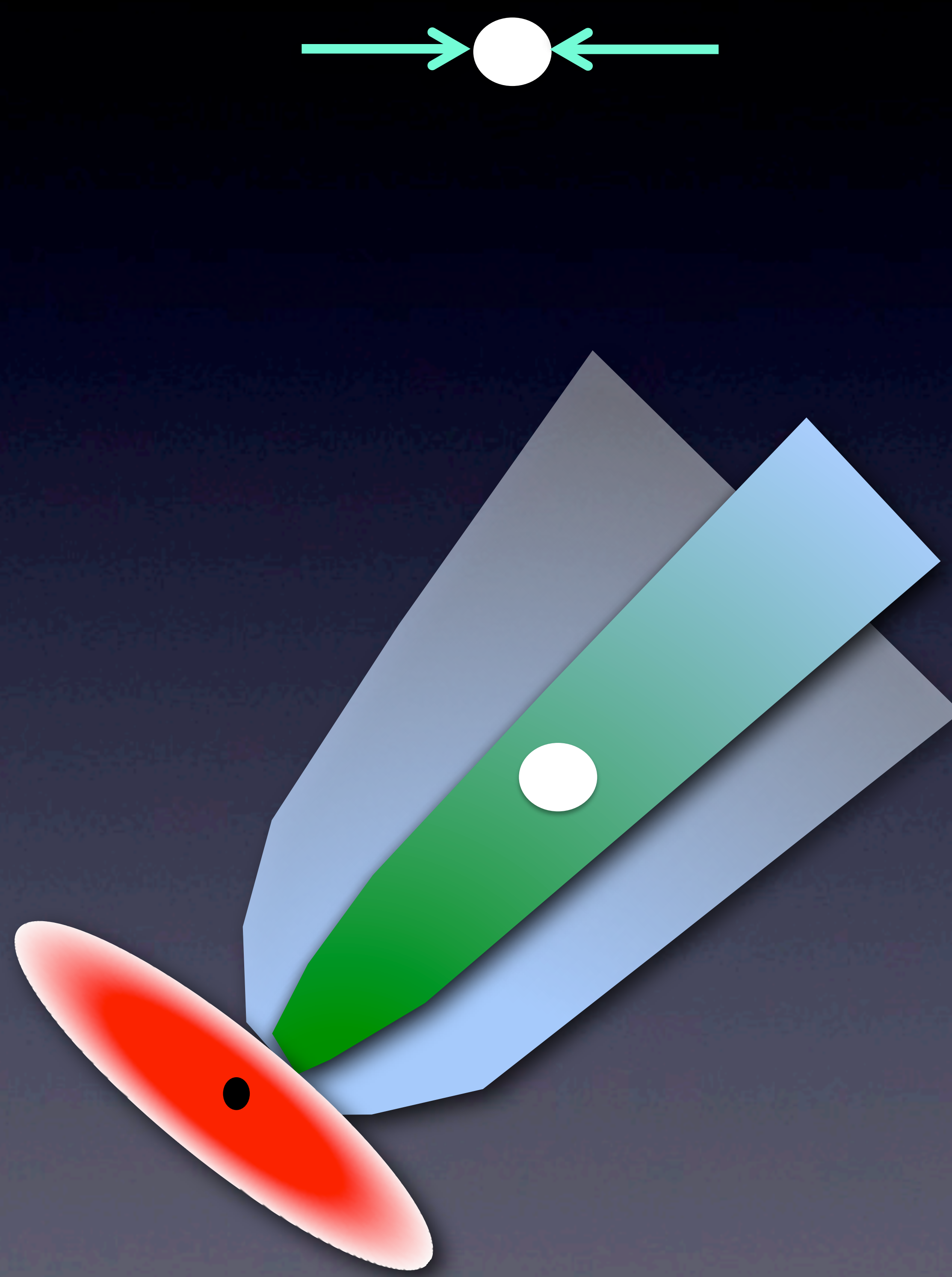
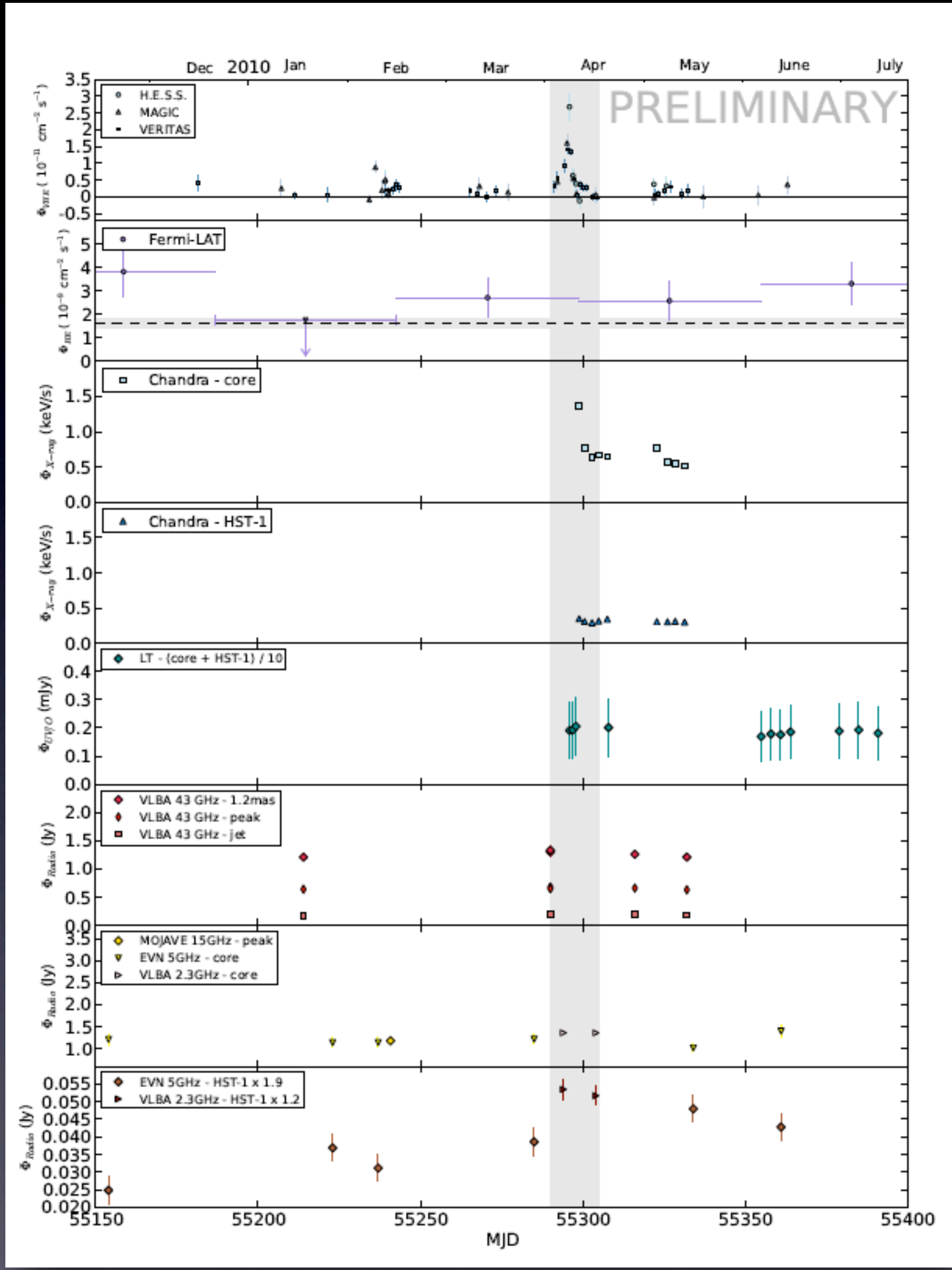


...MW observations are necessary to **localize where the gamma-ray photons are produced** and possibly distinguish between the two scenarios.

Up to know MW studies limited to FRI radio galaxies

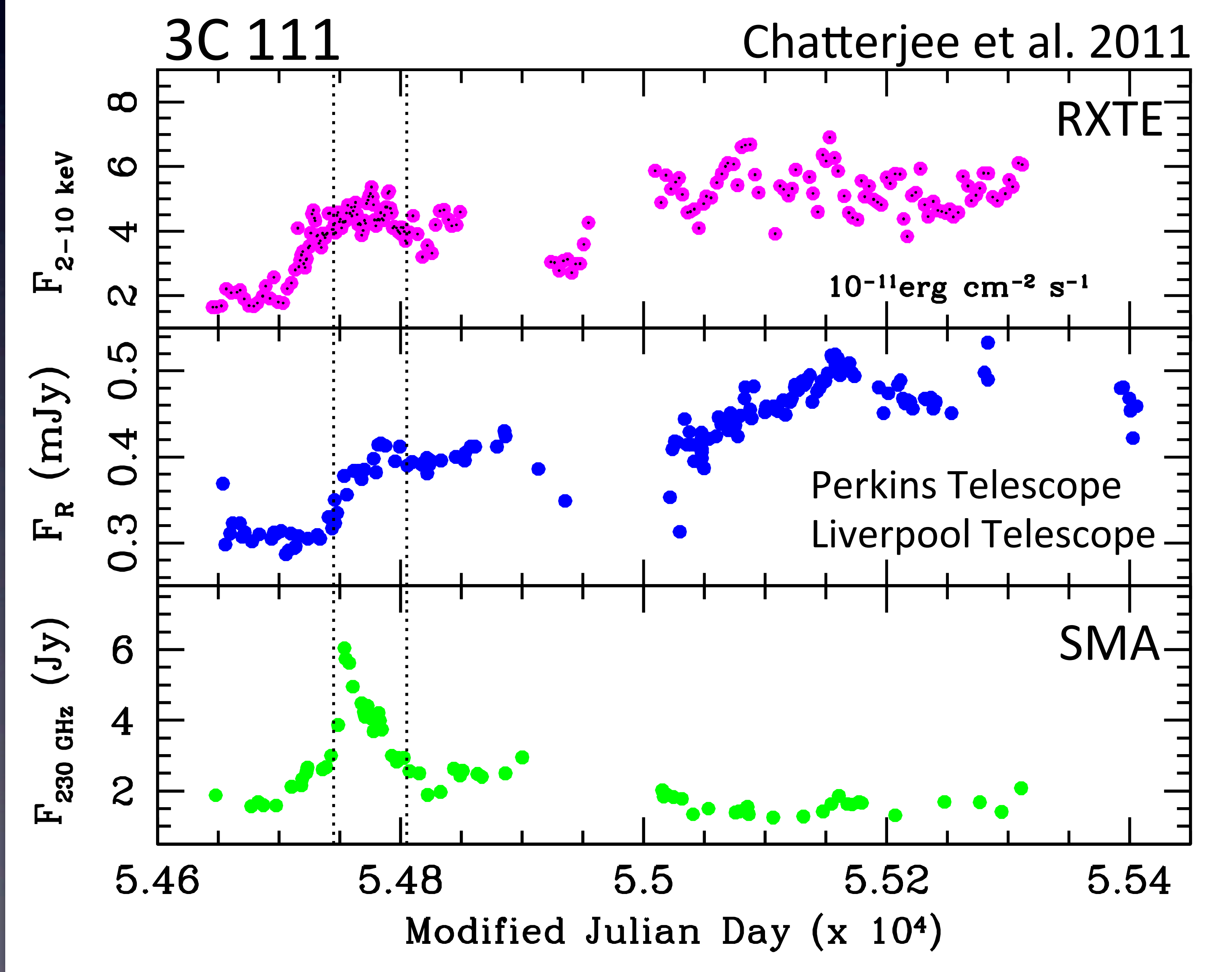
M87



Raue et al. 2012

The first MW study on an FRII radio galaxy has been carried out recently

(Grandi, Torresi & Stanghellini 2012)



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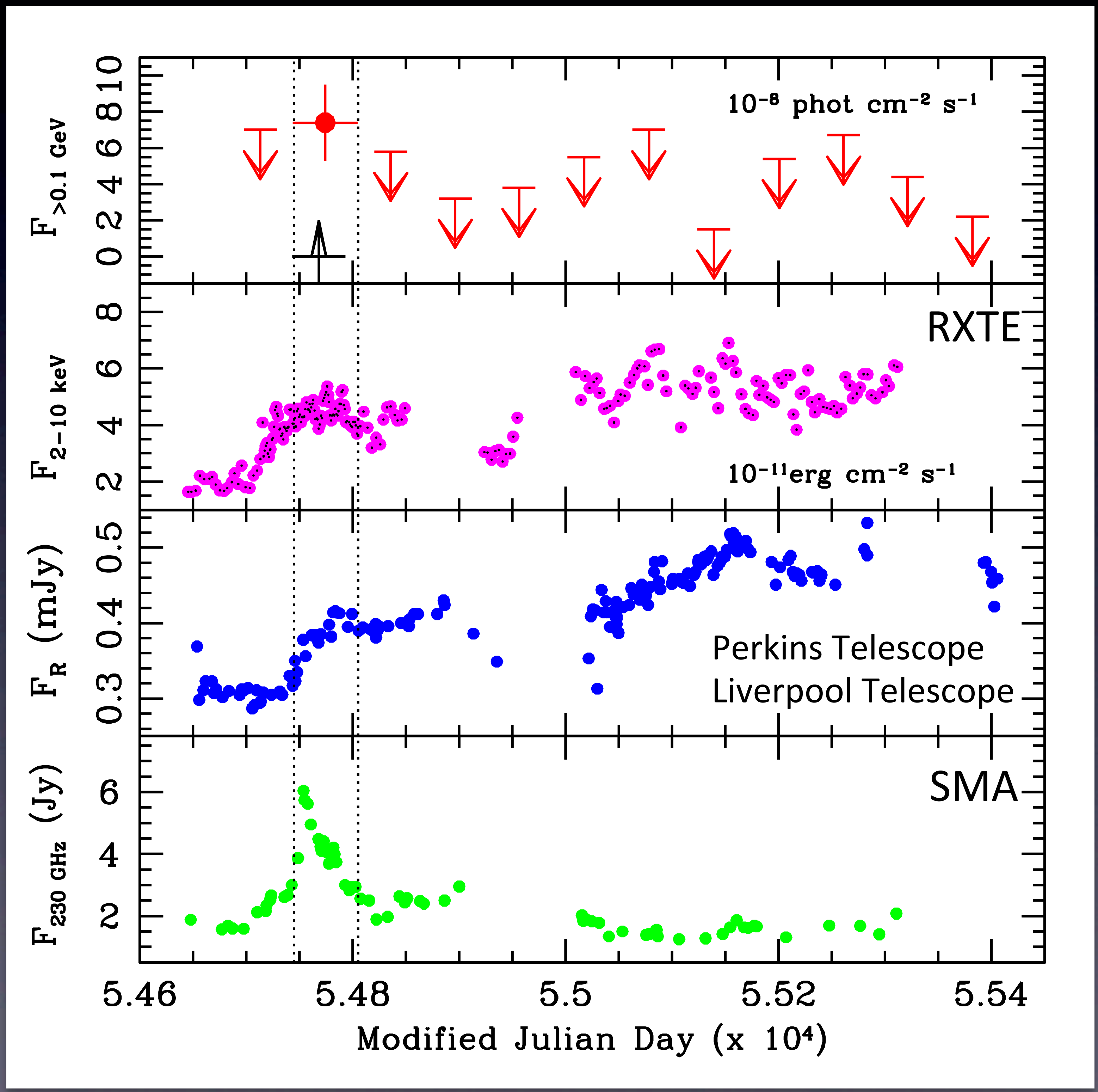


24-month LC
bin= 2 months

Gamma-ray flare simultaneous to mm-optical-X-ray outburst

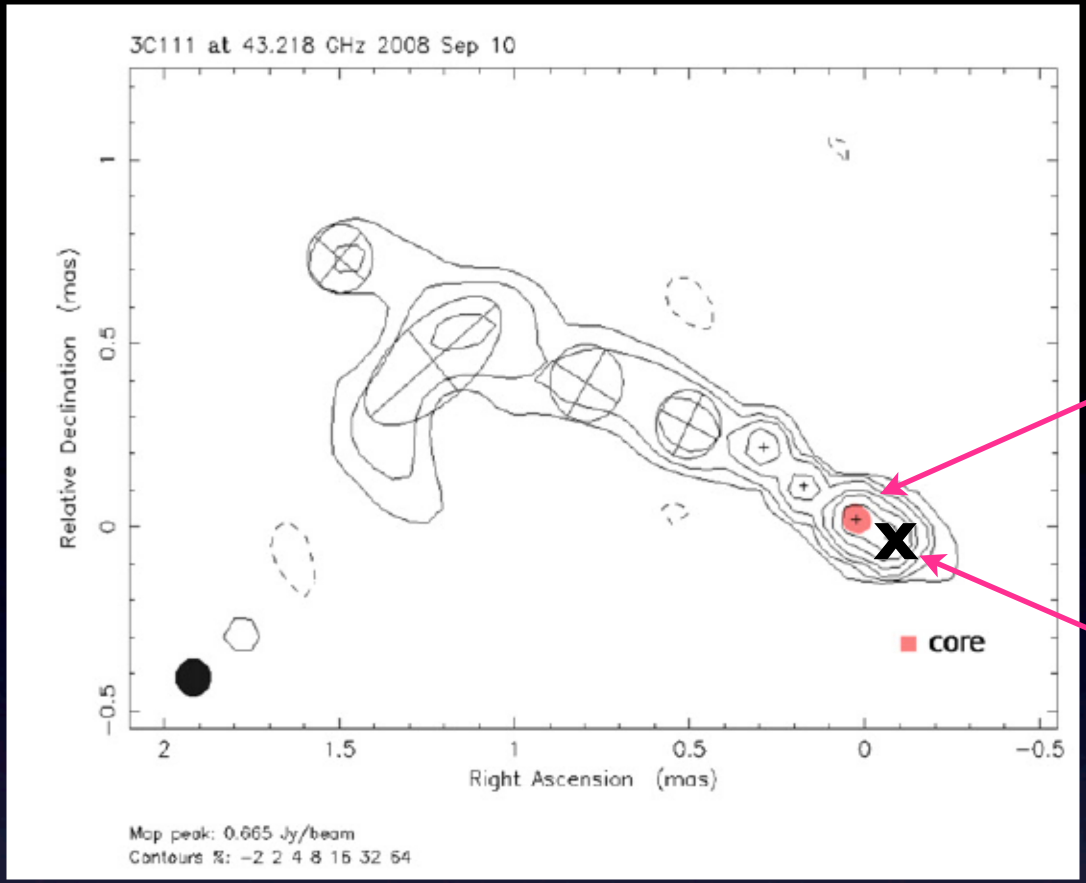
↓

Co-spatiality of the event

↓

Radio knot ejection

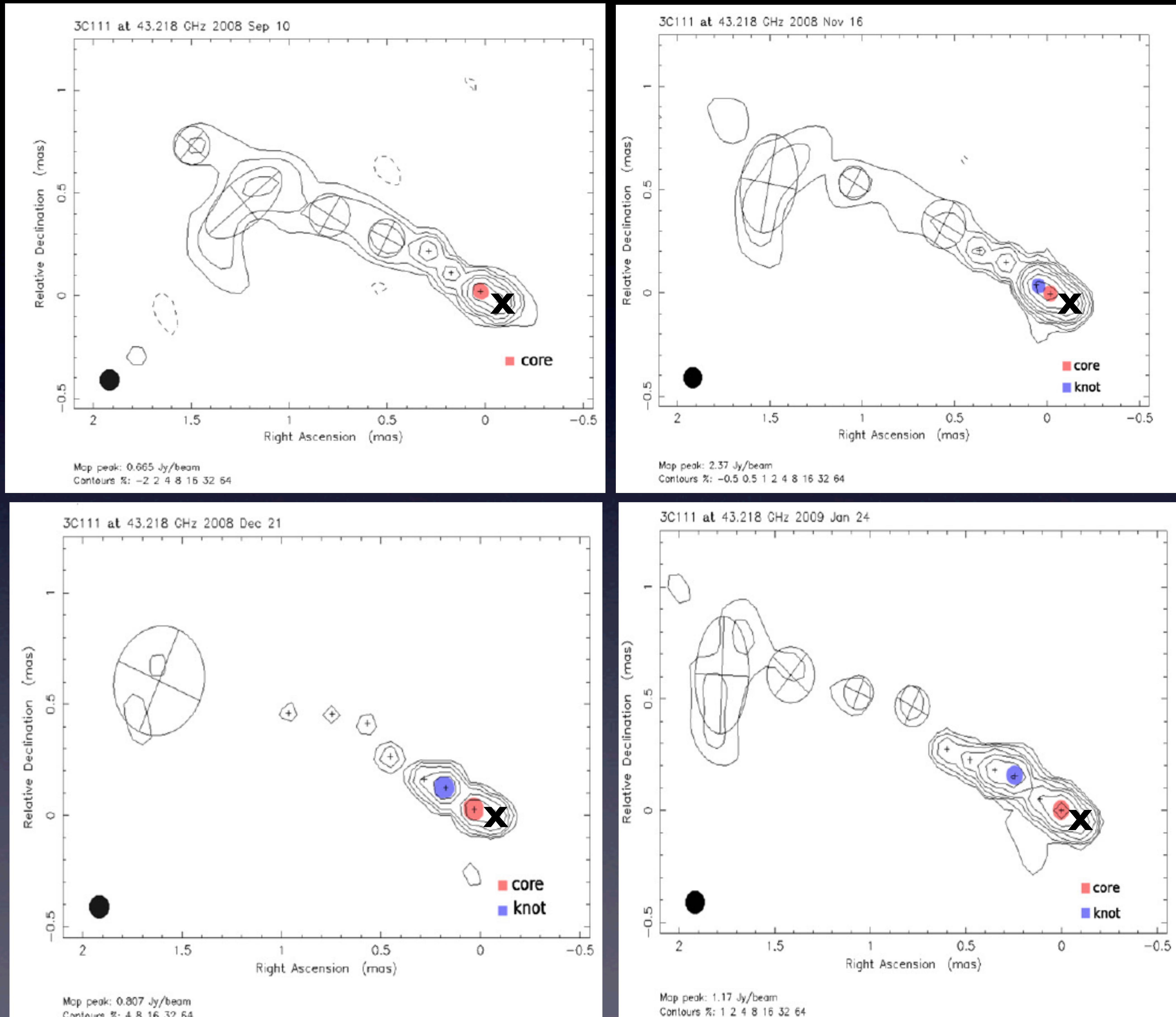
VLBA 43 GHz images: imaging the gamma-ray emitting region



stable component (core)

possible counter-jet

VLBA 43 GHz images: imaging the gamma-ray emitting region



Gamma-ray flare simultaneous to mm-optical-X-ray outburst

↓

Co-spatiality of the event

↓

Radio knot ejection

↓

The gamma-ray source must be **compact** (Δt=30-60 d => $R<0.1$ pc) and **located in the radio core region** ($R_{core}<0.3$ pc)

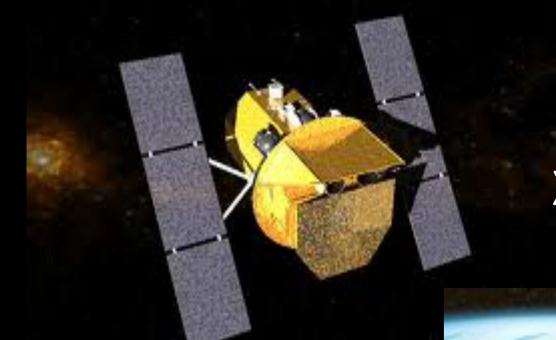
The TANGO multiwavelength campaign

TANGO (**T**iming **A**nalysis of **N**on blazar **G**amma-ray **O**bjects) is a multiwavelength campaign on Misaligned AGN (MAGN) that aims at studying the temporal variability of these objects from radio-to-gamma-rays.

Cassini 152 cm telescope (Loiano, Italy)

The Rapid Eye Mount (REM) 60 cm telescope (La Silla, Chile)

The Northern Cross (Medicina, Italy)



The Swift X-ray satellite

The XMM-Newton satellite

The Fermi gamma-ray satellite

https://hangar.iasfbo.inaf.it/tango/index.html

People involved in TANGO

Fermi-LAT collaborators:

E. Torresi, P. Grandi, G. Malaguti (INAF/IASF Bologna)
G. Tosti, **F. D'Ammando** (University of Perugia)
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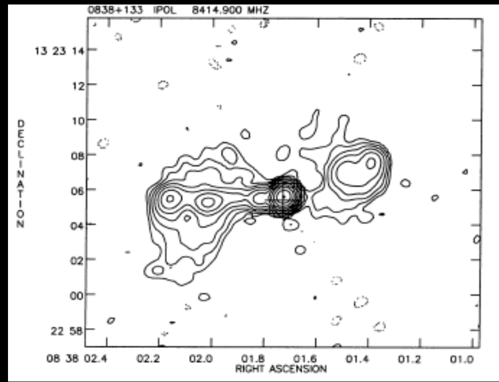
S. Ciprini, S. Cutini, D. Gasparrini (ASDC Rome)
D. Bastieri, S. Buson (University of Padova)
C. Romoli (University of Dublin)
R. Ojha (NASA/GSFC)
S. Larsson (Stockholm University)
T. Cheung (NRC/NRL)
M. Ajello (Berkeley University)
L. Stawarz (ISAS/JAXA, OA UJ Poland)

External collaborators:

A. De Rosa (INAF/IASF Bologna)
S. Galleti, I. Bruni, R. Gualandi, V. Zitelli (INAF/OA Bologna)

3C 207 FRII- SSRQ at z=0.680

(Torresi et al. 2013 in prep.)



Fermi-LAT

Swift/XRT

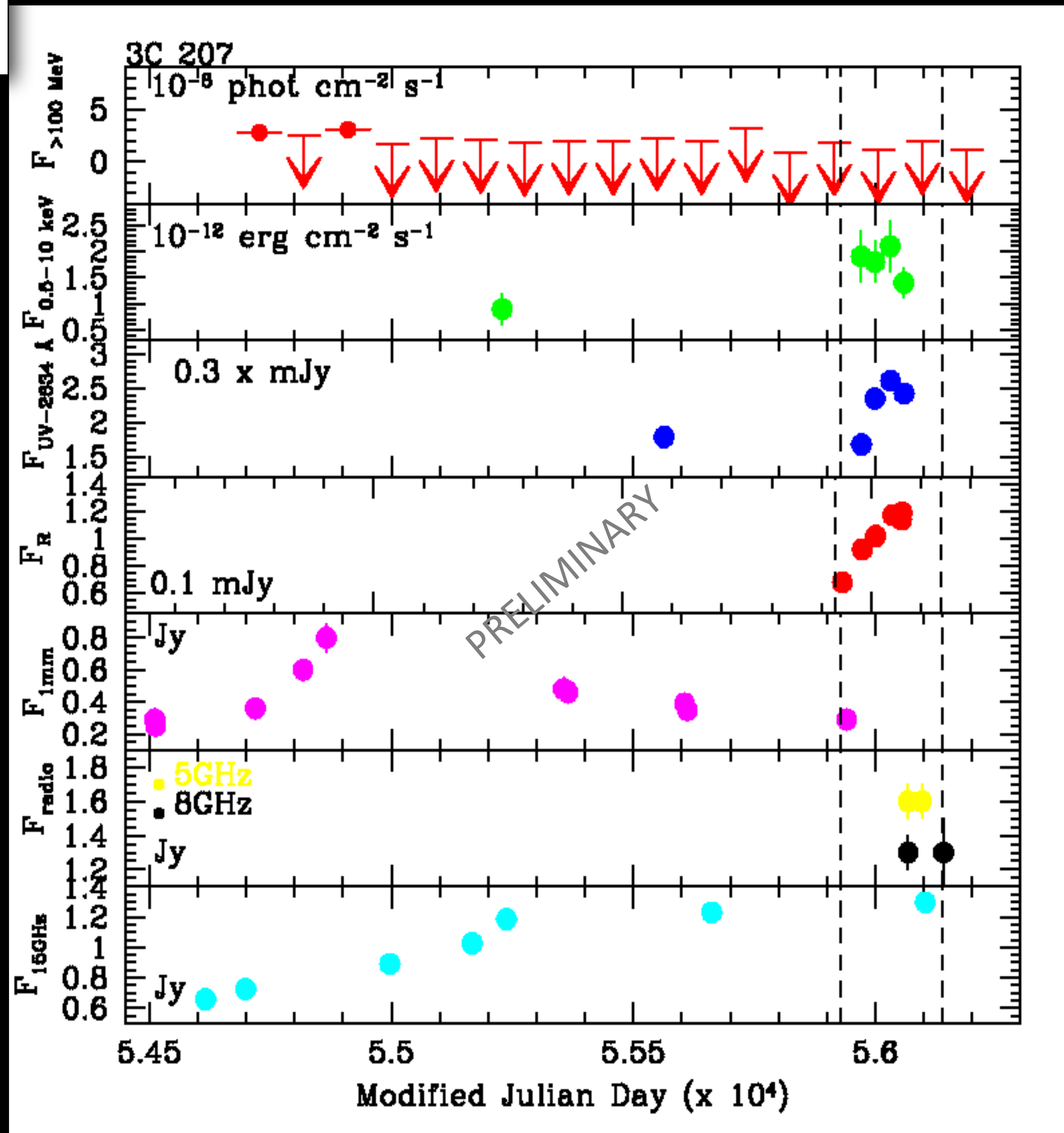
Swift/UVOT

Cassini Telescope

SMA

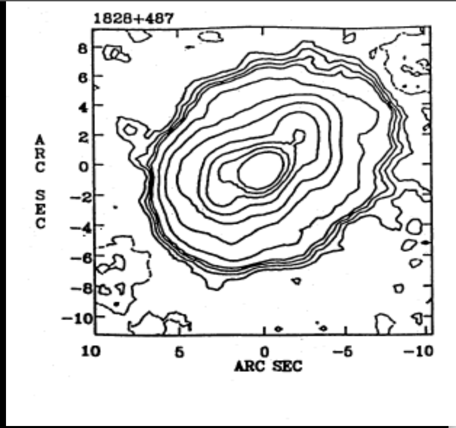
Medicina

MOJAVE 15 GHz



51-month LC
Bin=3 months

FEB 2008 ⟷ NOV 2012



3C 380 FRII- SSRQ at z=0.692

(Torresi et al. 2013 in prep.)

Fermi-LAT

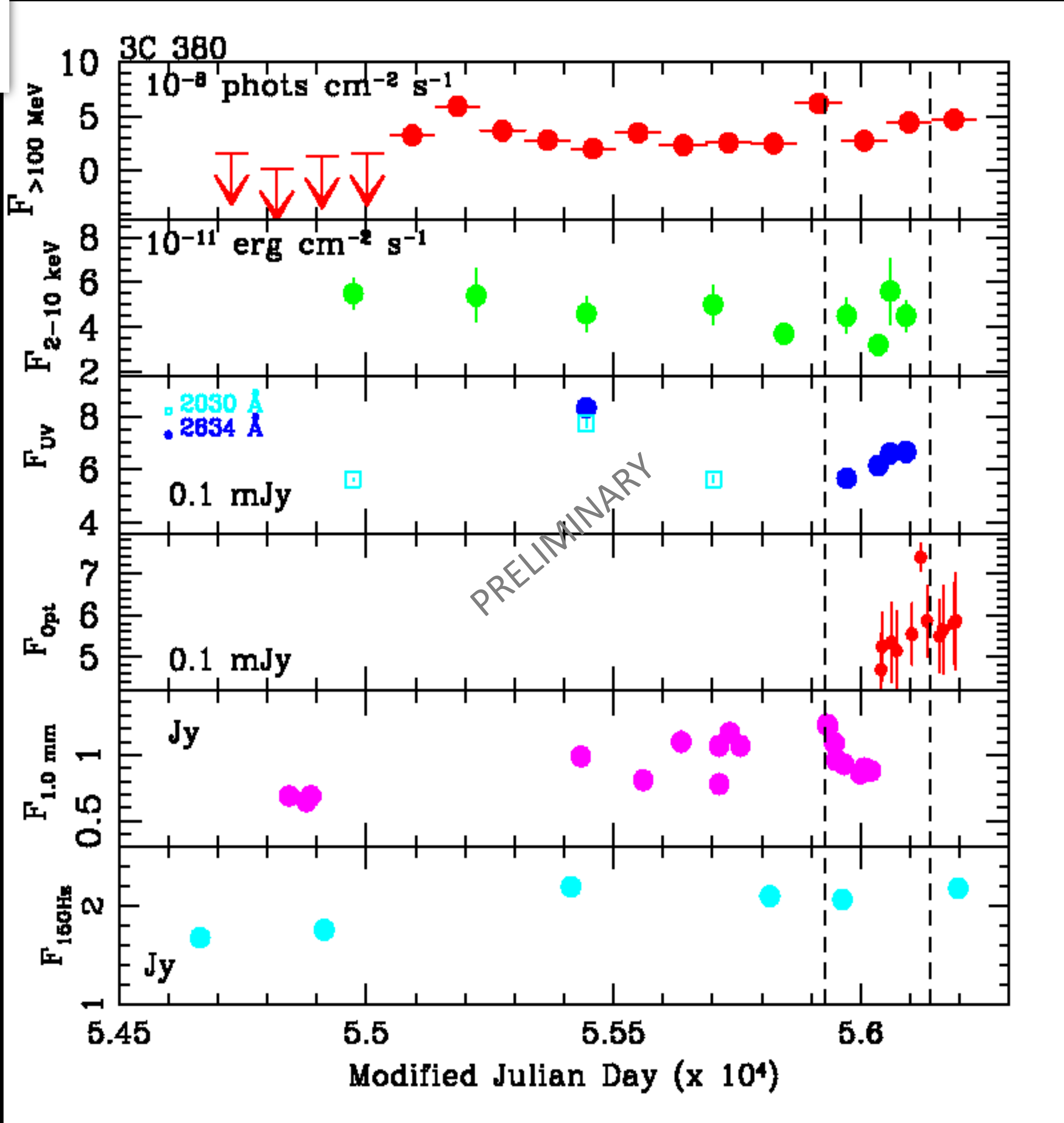
Swift/XRT

Swift/UVOT

Cassini Telescope

SMA

MOJAVE 15 GHz



51-month LC
Bin=3 months

Conclusions

✤ **Fermi has given an invaluable contribution to the discovery of MAGNs as a new class of gamma-ray sources;**

✤ **FRIs are more easily detected by LAT than FRIIs:**

- the distance hypothesis seems to be ruled out;
- the jet is structured: the presence of a less structured (or less decelerated) jet could disfavor the detection of FRII sources;
- the gamma-ray beaming cone of SSC processes (FRI) is larger than that of the EC processes (FRII) favoring FRIs detection;

✤ **MW studies are fundamental to determine the location of the high-energy dissipation zone and to distinguish between the 'near site' and 'far site' scenarios;**

✤ The TANGO MW campaign has already produced very interesting results on the two SSRQs (3C 207 & 3C 380) of the MAGNs sample.