High-energy observations of γ–ray loud AGN

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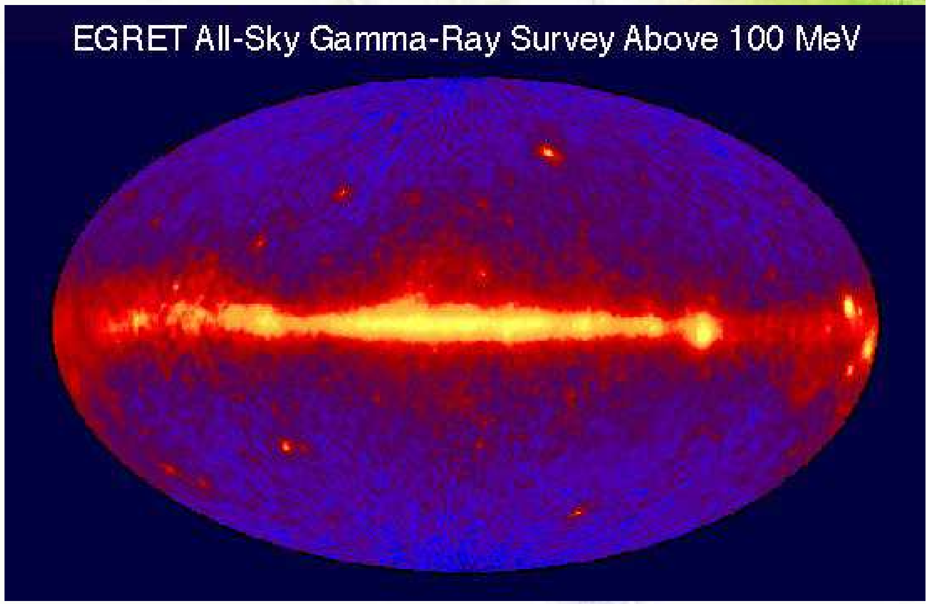
And many others…

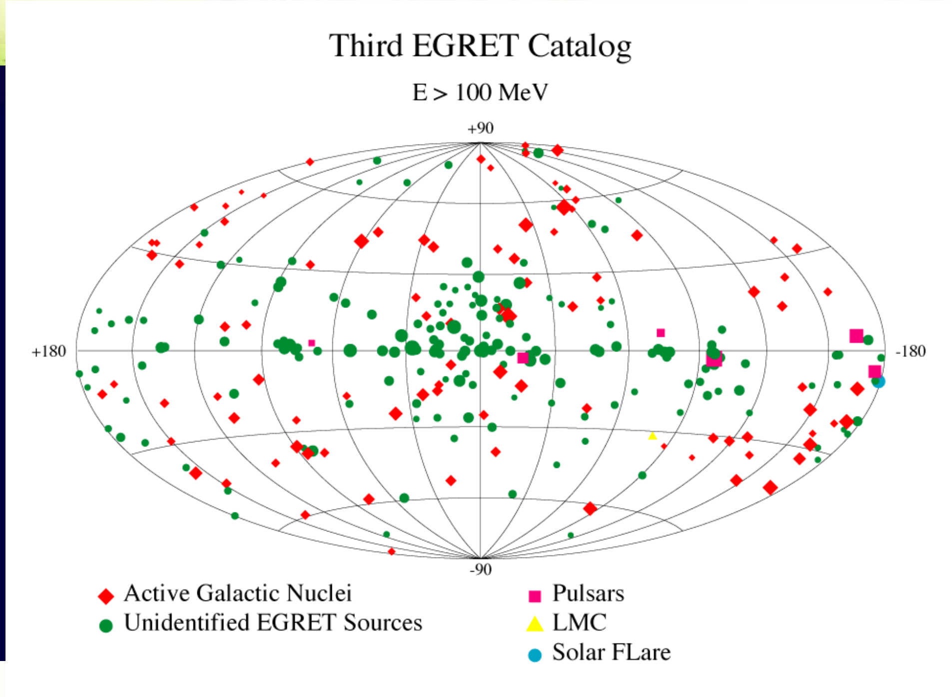
7th Italian National Conference on AGN (AGN7)
Montagnana (PD), 23-26 May 2006

A bit of history…

✓ **First detection** of γ-rays (50-500 MeV) from an AGN (3C 273) by ESA satellite *COS-B* (Swanenburg et al. 1978);

✓ Breakthrough with NASA satellite *CGRO/EGRET*, with 271 point sources detected at E>100 MeV (Hartman et al. 1999), 93 of them identified with **blazars** and 2 with **radiogalaxies**;



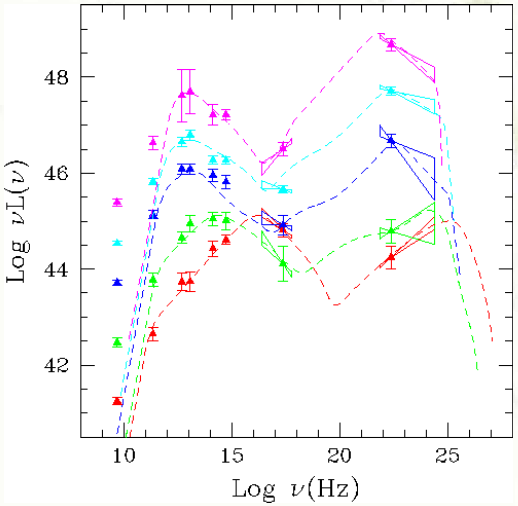


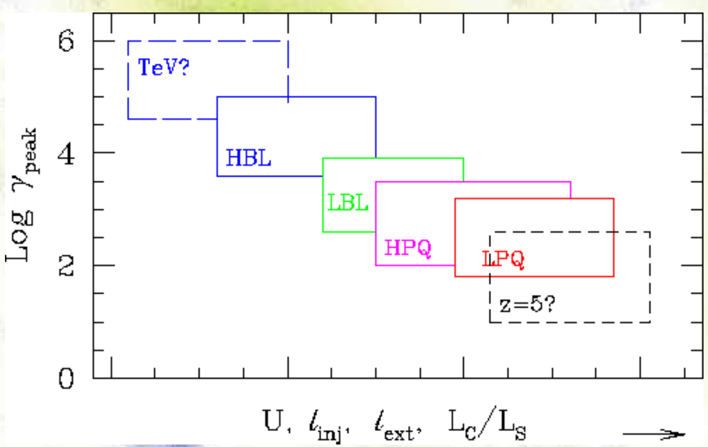
✓ γ-ray loudness strongly biased by EGRET sensitivity and non-uniform exposure map; **here we consider "γ-ray loud" an AGN detected by EGRET at E>100 MeV**;

A bit of what…

The **“blazar standard model”**: SMBH with a relativistic jet pointed toward the observer with small angles (<10°); the relativistic motion can account for negligible γ-ray attenuation.

The **“blazar sequence”** (Fossati et al. 1998; Ghisellini et al. 1998).





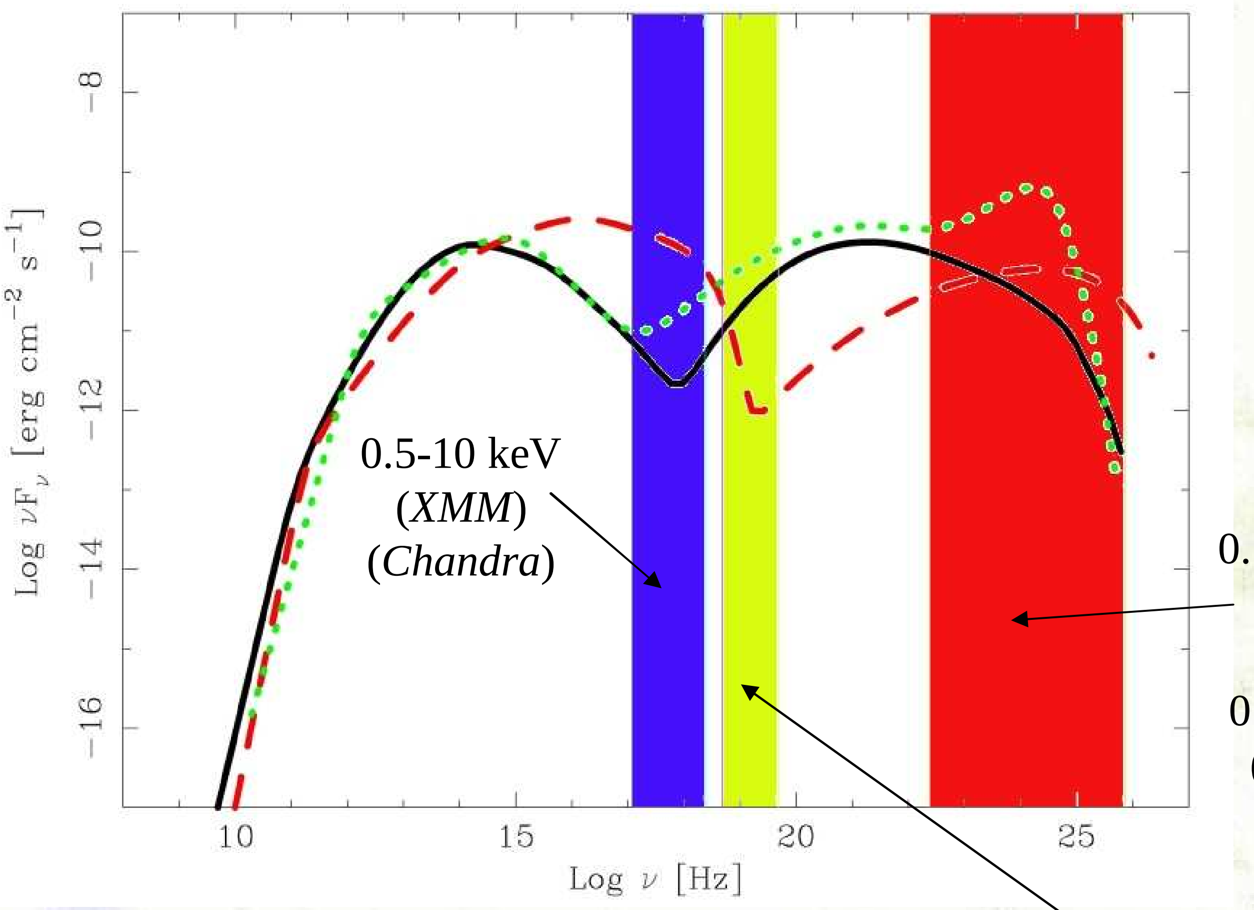
See, however, Padovani et al. (2003).

Open questions concerning the **physics** of γ–ray loud AGN: γ–ray generation mechanisms and places, dependence on viewing angle (link with radiogalaxies), composition of jets, disk-jet coupling, scaling laws for μquasar, and many more!

A bit of how…

Multiwavelength variability appears to be a key issue in understanding the blazar phenomenon: it should allow to gain insights on the geometry of the emitting region, acceleration/deceleration processes, test models (SSC, EC, others?), …

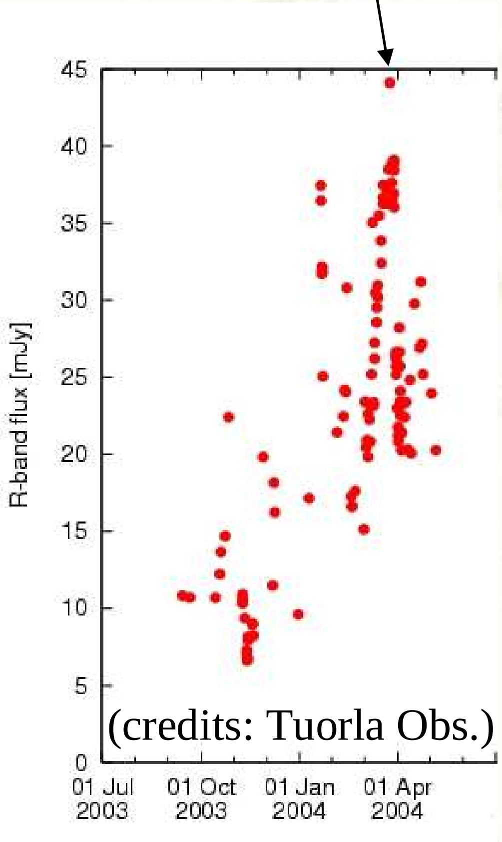
Multiwavelength variability: X-rays and hard X-rays energy bands are **crucial** in understanding the physics of γ-ray loud AGN.



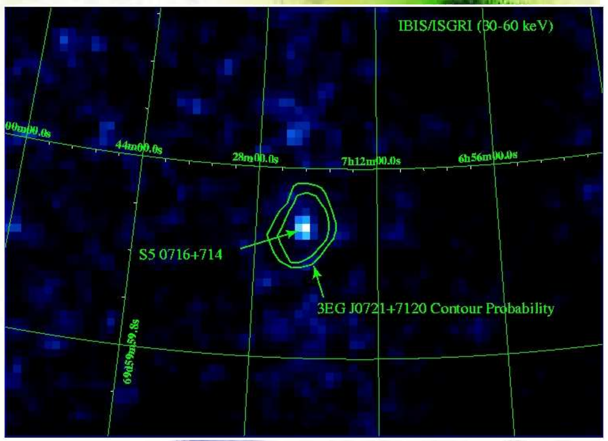
Continuous line: typical low frequency peaked BL Lac (LBL)
Dashed line: typical high frequency peaked BL Lac (HBL)
Dotted line: typical flat-spectrum radio quasar (FSRQ)

TOO activities to observe blazars in outburst: S5 0716+714

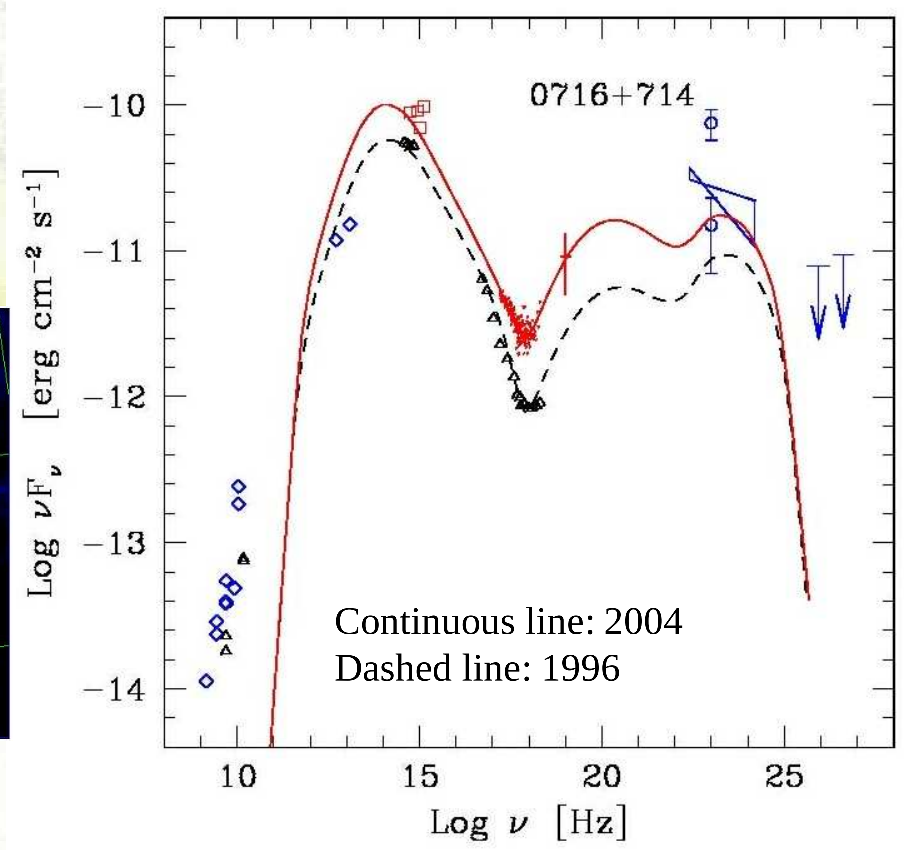
Optical outburst at the end of March 2004: **historical peak** recorded on 27 March 2004 with **R=12.1**! (Ostorero et al., in prep.)



Pian et al., 2005, A&A 429, 427



Model by Ghisellini, Celotti & Costamante (2002)



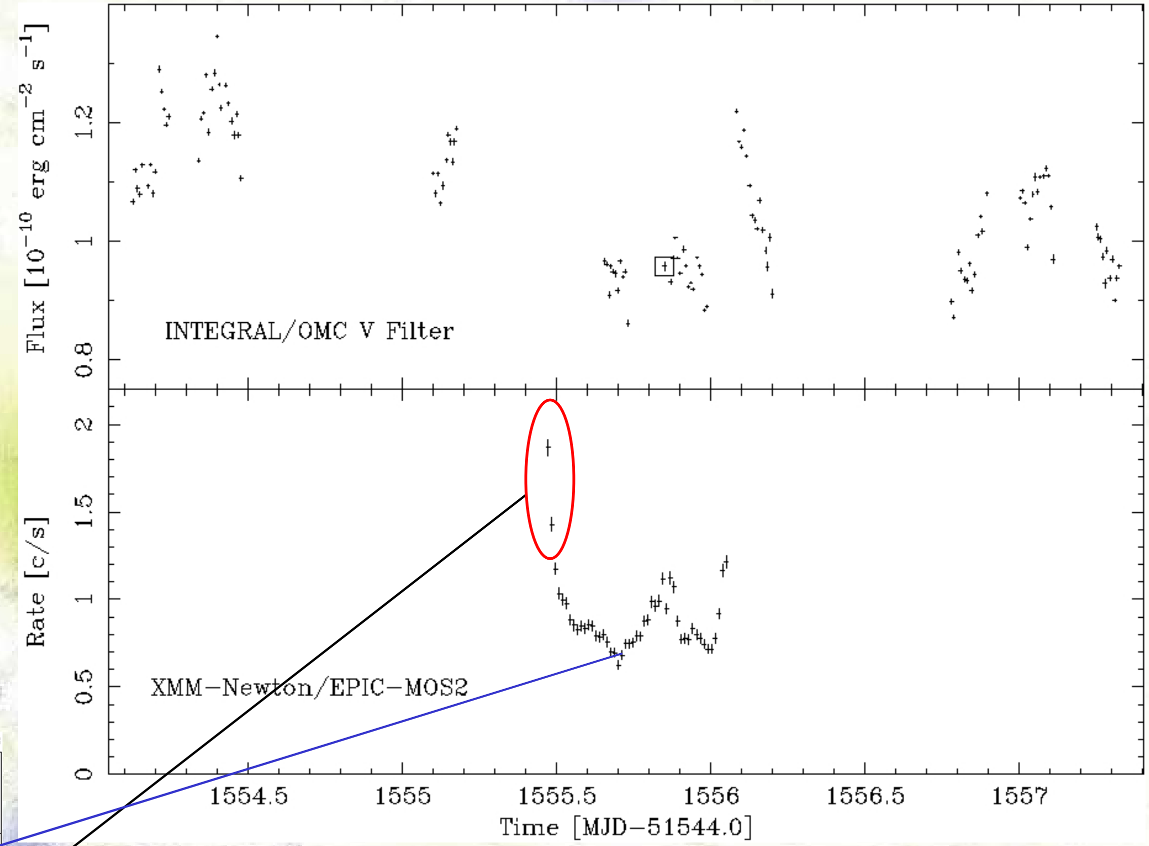
TOO with *INTEGRAL* (PI E. Pian; 2-7 April 2004; 280 ks) and *XMM-Newton* (PI G. Tagliaferri; 4-5 April 2004; 50 ks): “too” late… the source was declining…

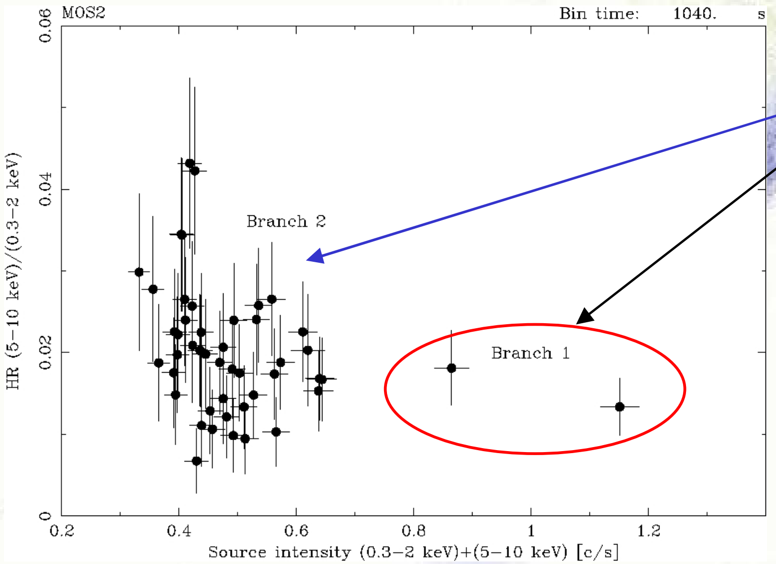
TOO activities to observe blazars in outburst: S5 0716+714

Long term variability (burst to quiescence; branch 1?):

➢ gradual decay afterburst probably due to escape of electrons from the processing regions or to a decrease of seed photons.

➢ from quiescence to outburst and viceversa (SED: 1996-2004): minor changes in the model parameters, except for the injected power (2.2×10^{42} erg/s in 1996; 4×10^{42} erg/s in 2004).





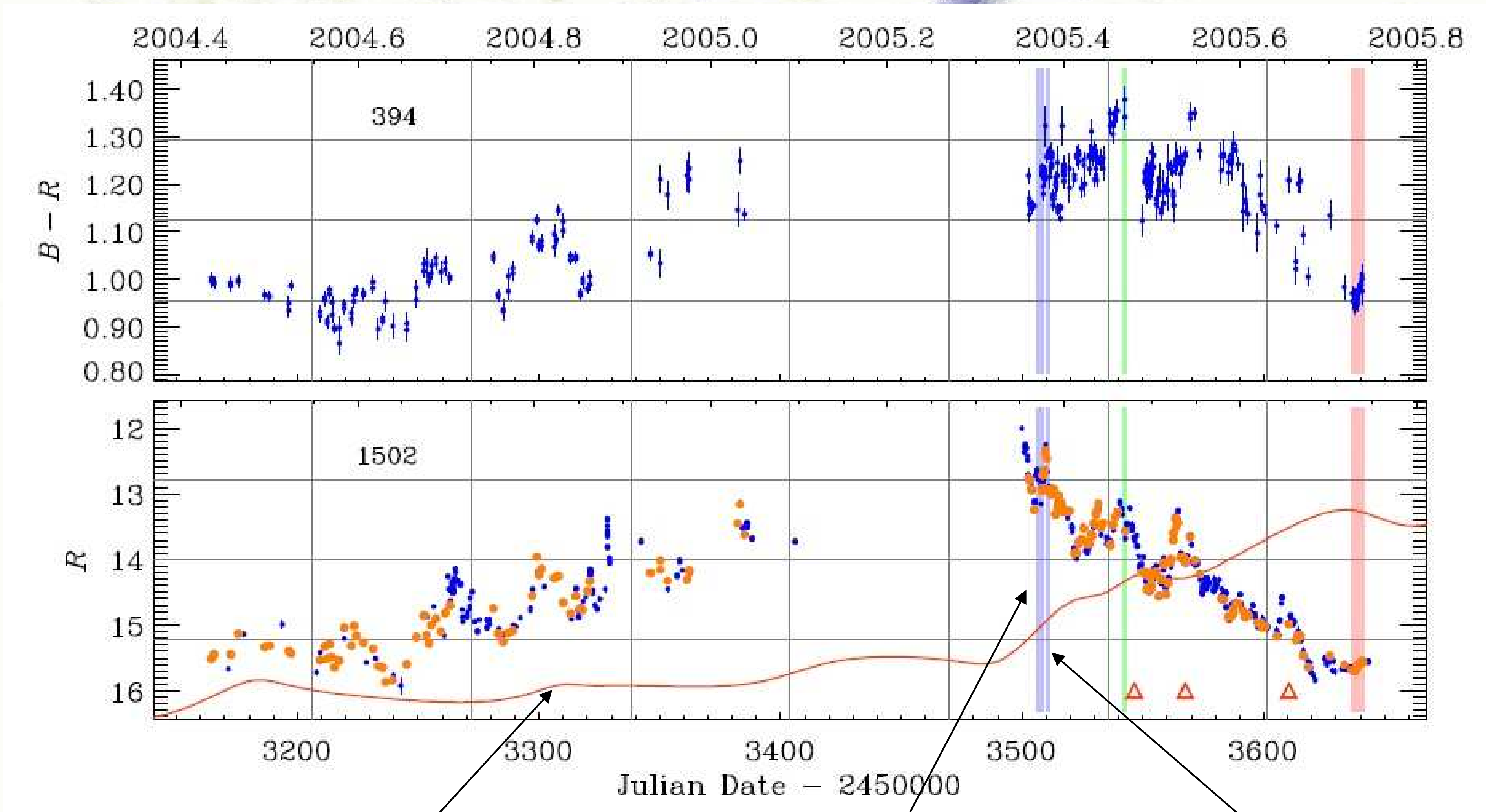
Short term variability (optical/X-ray flares; branch 2): probably due to changes in the slope of the electrons distribution.

Foschini et al., 2006, astro-ph/0604600

TOO activities to observe blazars in outburst: 3C 454.3

Long outburst of 3C 454.3 in April-May 2005.

Whole Earth Blazar Telescope campaign (Villata et al. 2006, astro-ph/0603386)



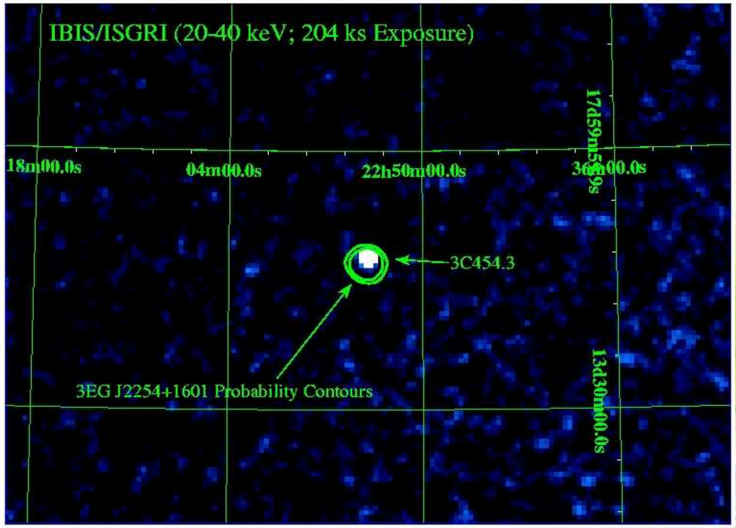
Radio 43 Ghz (VLBA)

INTEGRAL (PI E. Pian)
15-18 May 2005

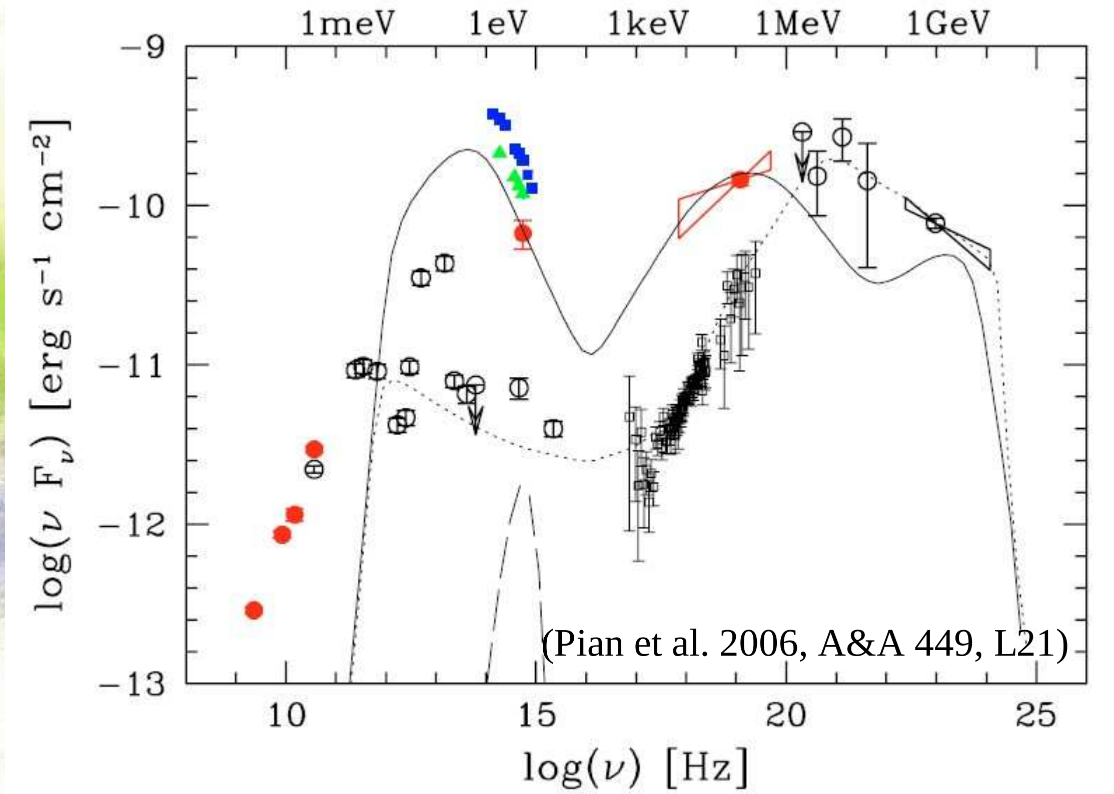
Chandra (PI F. Nicastro)
19-20 May 2005

TOO activities to observe blazars in outburst: 3C 454.3

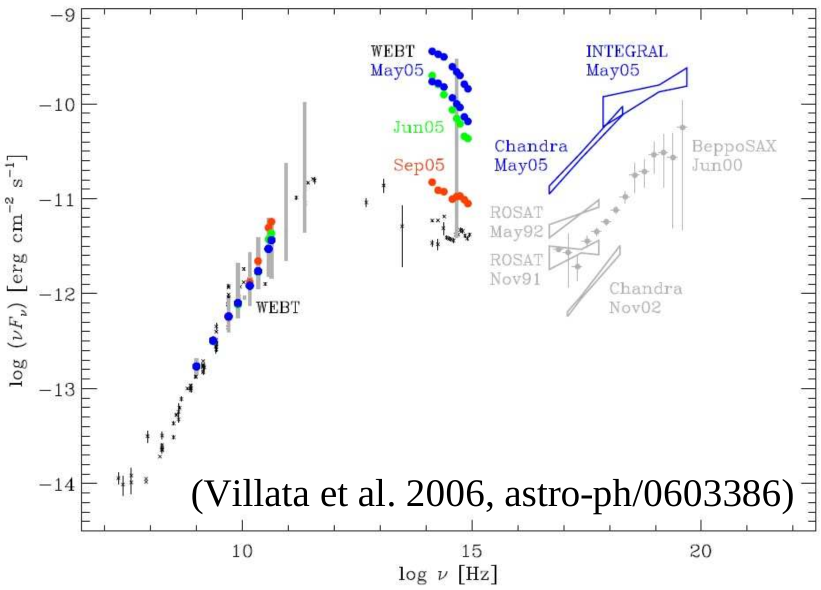
TOO with *INTEGRAL* (PI E. Pian)



Model by Ghisellini, Celotti & Costamante (2002)



(Pian et al. 2006, A&A 449, L21)



(Villata et al. 2006, astro-ph/0603386)

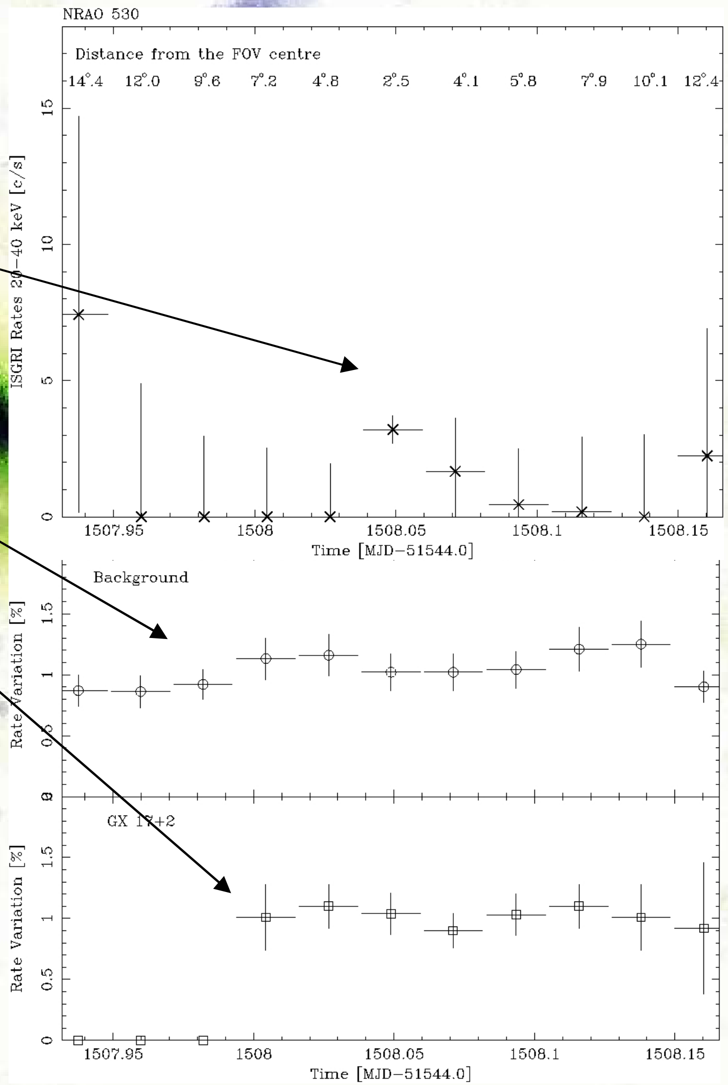
Studies on the **post-outburst** properties: the new **WEBT** campaign on 3C 454.3 with continuous radio to optical monitoring and three *XMM-Newton* pointings. See details at: http://www.to.astro.it/blazars/webt→campaigns

Search into public archives for lost outbursts: NRAO 530

Occurred on 17 February 2004 and detected serendipitously by IBIS/ISGRI on board *INTEGRAL* during the Galactic Centre Deep Exposure (GCDE).

Peak flux ≈ 2×10^{-10} erg cm^{-2} s^{-1} in the 20-40 keV energy band in a time scale of less than 1 hr.

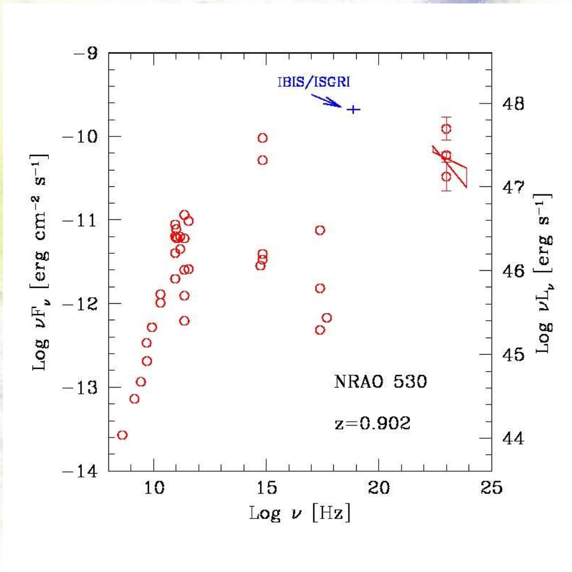
Background: stable
GX 17+2 (that has the ISGRI SPSF overlapping with NRAO530): stable



Two *Swift*/XRT (0.3-10 keV) snapshots show **no other X-ray sources** inside the 3 arcmin IBIS/ISGRI error circle.

Search into public archives for lost outburst: NRAO 530

- NRAO 530 is known to display strong and erratic variability: up to Δmag $\approx$ 3 at optical wavelengths (Pollock et al. 1979; Webb et al. 1988); up to a factor 6 in flux in the EGRET energy band (Mukherjee et al. 1997).
- **First event of this type** in the hard X-rays (and in a FSRQ), exceptional, but still consistent with the SED.



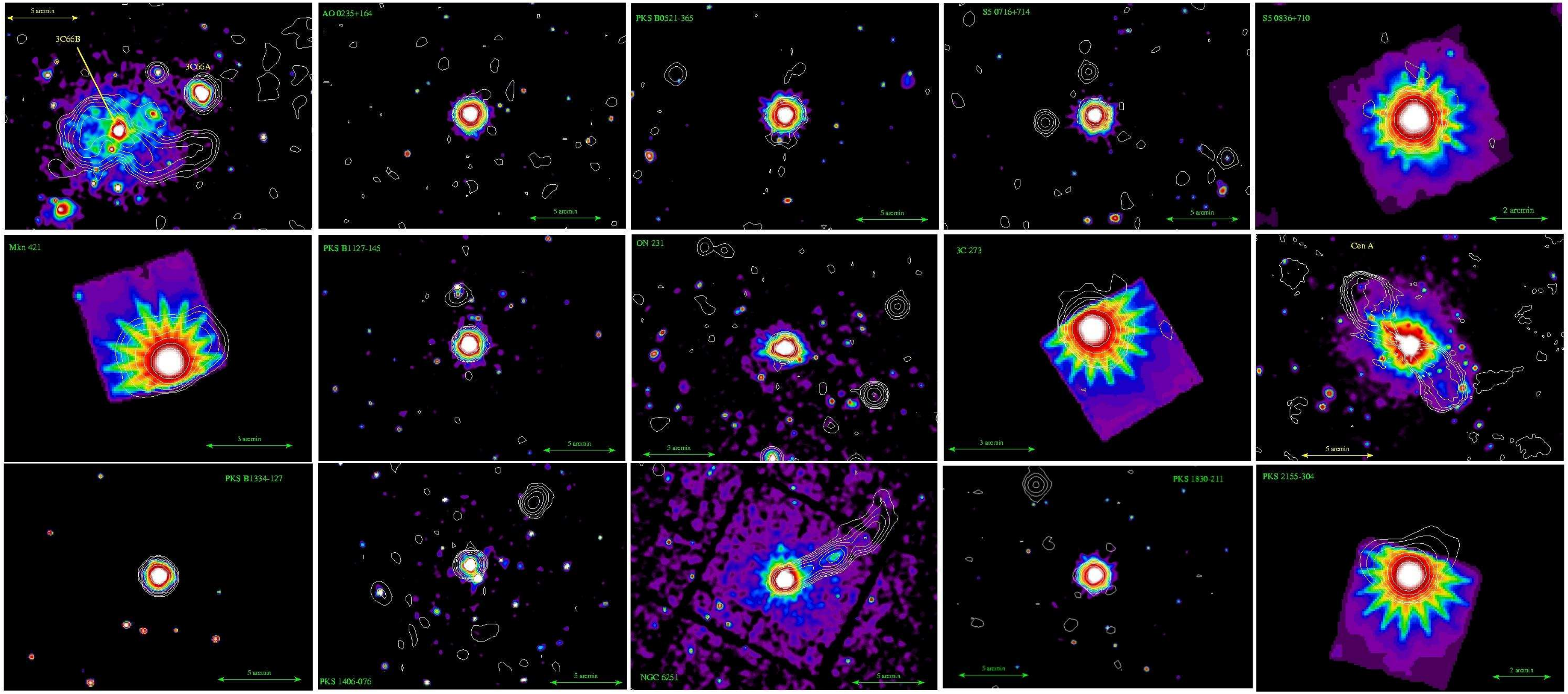
- Search for simultaneous or nearly simultaneous data at other wavelengths: only one **radio** observation at 2 cm (**MOJAVE Project**, Lister & Homan, 2005, AJ 130, 1389) performed on 11 February 2004 revealed a moderate increase of the **polarization**.
- Possible explanations: unsteadyness of the jet flow, that might be due to a single non stationary shock (e.g. Hughes et al. 1985) or to a collision of two relativistic plasma shells (internal shock, Spada et al. 2001). Anything else?

For more details: Foschini et al. 2006, A&A 450, 77

Studies on overall properties based on public archival data

Study of a sample of γ-ray emitting AGN (Foschini et al., astro-ph/0603268):

✓ 2 HBL (Mkn 421; PKS 2155-304)
✓ 4 LBL (3C66 A; AO 0235+164; S5 0716+714; ON 231)
✓ 7 FSRQ (PKS 0521-365; S5 0836+710; PKS 1127-145; 3C 273; PKS 1334-127; PKS 1406-076; PKS 1830-211)
✓ 2 RG (Cen A; NGC 6251)



The XMM-Newton view of Gamma-Ray Loud AGN

Image courtesy of Luigi Foschini (INAF/IASF-Bologna, Italy)

European Space Agency

Studies on overall properties based on public archival data

Averages on best fits

Name (1)	N_H (2)	Γ/Γ_1 (3)	Γ_2 (4)	E_{break} (5)
0219 + 428	Gal.	$2.91^{+0.12}_{-0.08}$	$2.23^{+0.10}_{-0.09}$	1.3 ± 0.2
AO 0235 + 164	Gal.	2.33 ± 0.04	2.1 ± 0.1	$3.3^{+0.7}_{-0.5}$
PKS 0521 − 365	Gal.	1.95 ± 0.03	1.74 ± 0.03	$1.5^{+0.3}_{-0.2}$
S5 0716 + 714	Gal.	2.70 ± 0.02	$1.98^{+0.08}_{-0.09}$	$2.3^{+0.2}_{-0.1}$
S5 0836 + 710	14 ± 3	1.379 ± 0.007	–	–
Mkn 421	Gal.	2.38 ± 0.09	2.7 ± 0.2	2.7 ± 1.0
PKS 1127 − 145	12^{+2}_{-1}	$1.40^{+0.08}_{-0.05}$	1.22 ± 0.06	$2.7^{+1.0}_{-0.8}$
ON 231	2.5 ± 0.6	2.77 ± 0.04	–	–
3C 273	Gal.	2.02 ± 0.08	1.67 ± 0.05	1.44 ± 0.08
Cen A	1523 ± 261	2.22 ± 0.06	–	–
PKS 1334 − 127	6.7 ± 0.9	1.80 ± 0.04	–	–
PKS 1406 − 076	Gal.	1.59 ± 0.01	–	–
NGC 6251	14 ± 1	$2.11^{+0.08}_{-0.06}$	1.78 ± 0.07	$2.5^{+0.3}_{-0.4}$
PKS 1830 − 211	63 ± 1	1.00 ± 0.09	1.32 ± 0.06	3.5 ± 0.7
PKS 2155 − 304	1.69 ± 0.06	2.9 ± 0.1	–	–
	Gal.	2.7 ± 0.1	2.94 ± 0.06	2.7 ± 0.7

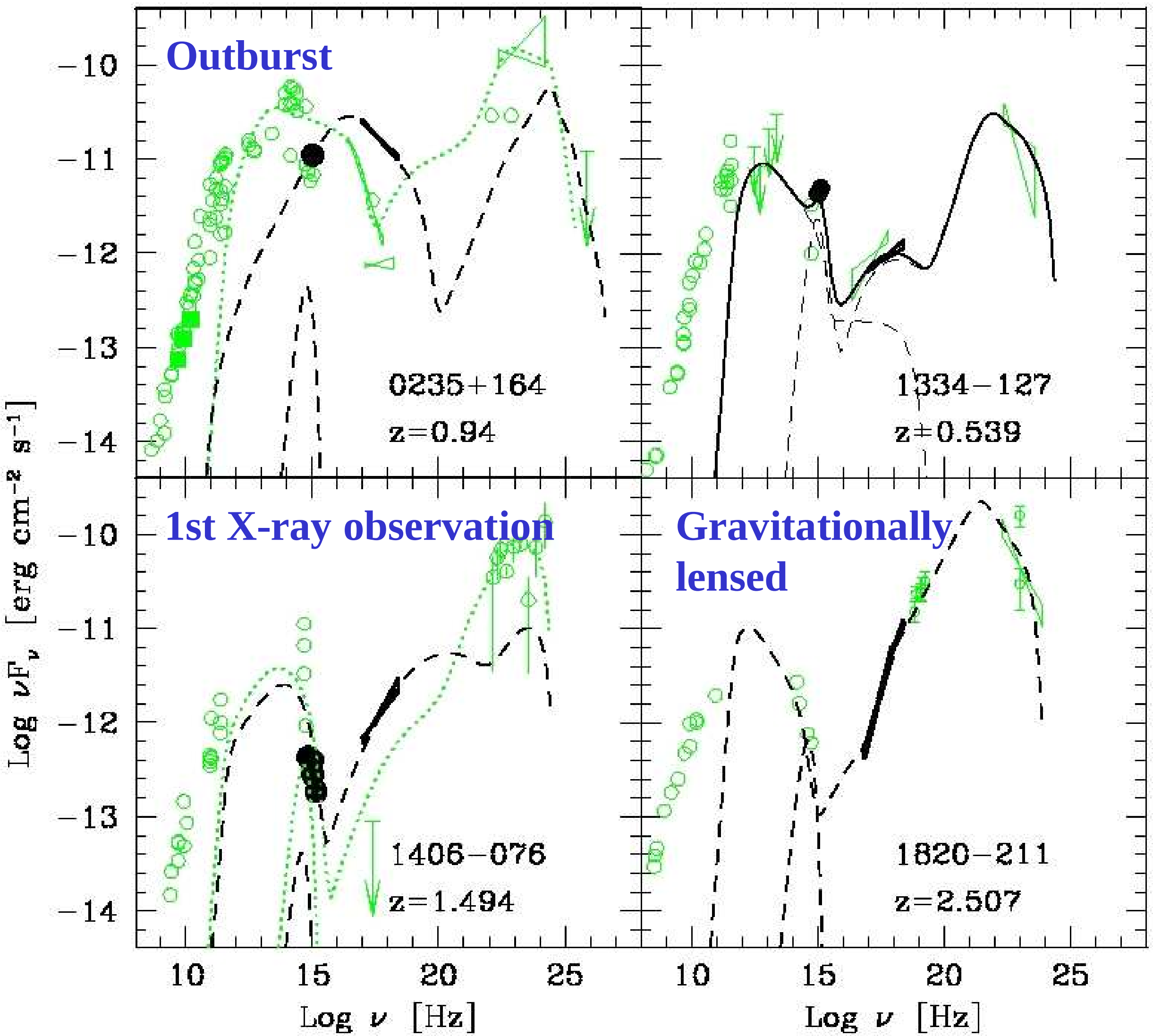
XMM-Newton 2000-2004 (Foschini et al. 2006, astro-ph/0603268)

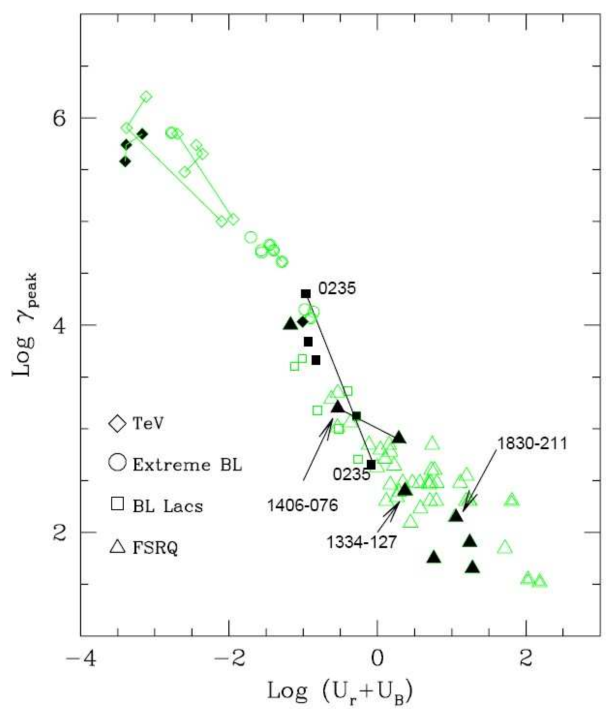
Name (1)	N_H (2)	Γ/Γ_1 (3)	Γ_2 (4)	E_{break} (5)
0219 + 428	Gal.	2.22 ± 0.06	–	–
AO 0235 + 164	Gal.	2.0 ± 0.1	–	–
PKS 0521 − 365	Gal.	1.74 ± 0.02	–	–
S5 0716 + 714	Gal.	2.5 ± 0.2	1.8 ± 0.1	3.0 ± 0.4
S5 0836 + 710	78^{+55}_{-35}	1.31 ± 0.02	–	–
Mkn 421	Gal.	1.9 ± 0.2	2.3 ± 0.3	1.3 ± 0.8
PKS 1127 − 145	Gal.	1.42 ± 0.05	–	–
ON 231	Gal.	2.58 ± 0.01	1.52 ± 0.06	2.8 ± 0.2
3C 273	Gal.	2.0 ± 0.1	1.603 ± 0.006	0.9 ± 0.3
	Gal.	1.58 ± 0.03	–	–
Cen A	1020^{+90}_{-40}	$1.80^{+0.03}_{-0.04}$	–	–
PKS 1334 − 127	–	–	–	–
PKS 1406 − 076	–	–	–	–
NGC 6251	9 ± 1	1.79 ± 0.06	–	–
PKS 1830 − 211	194^{+28}_{-25}	1.09 ± 0.05	–	–
PKS 2155 − 304	Gal.	2.3 ± 0.1	2.8 ± 0.1	1.7 ± 0.2

BeppoSAX 1996-2002

(Giommi et al. 2002; Donato et al. 2005) [Cen A: Grandi et al. 2003; NGC 6251: Chiaberge et al. 2003; Guainazzi et al. 2003] PKS 1830-211: Chandra+INTEGRAL, De Rosa et al. (2005).

Studies on overall properties based on public archival data
New or peculiar SED with respect to Ghisellini et al. (1998)





Studies on overall properties based on public archival data

Grandi & Palumbo (2004, Science 306, 998) **first disentangled** the “thermal” and the “non-thermal” components in 3C273 by using *BeppoSAX* data.

Decreasing trend of the radio flux.

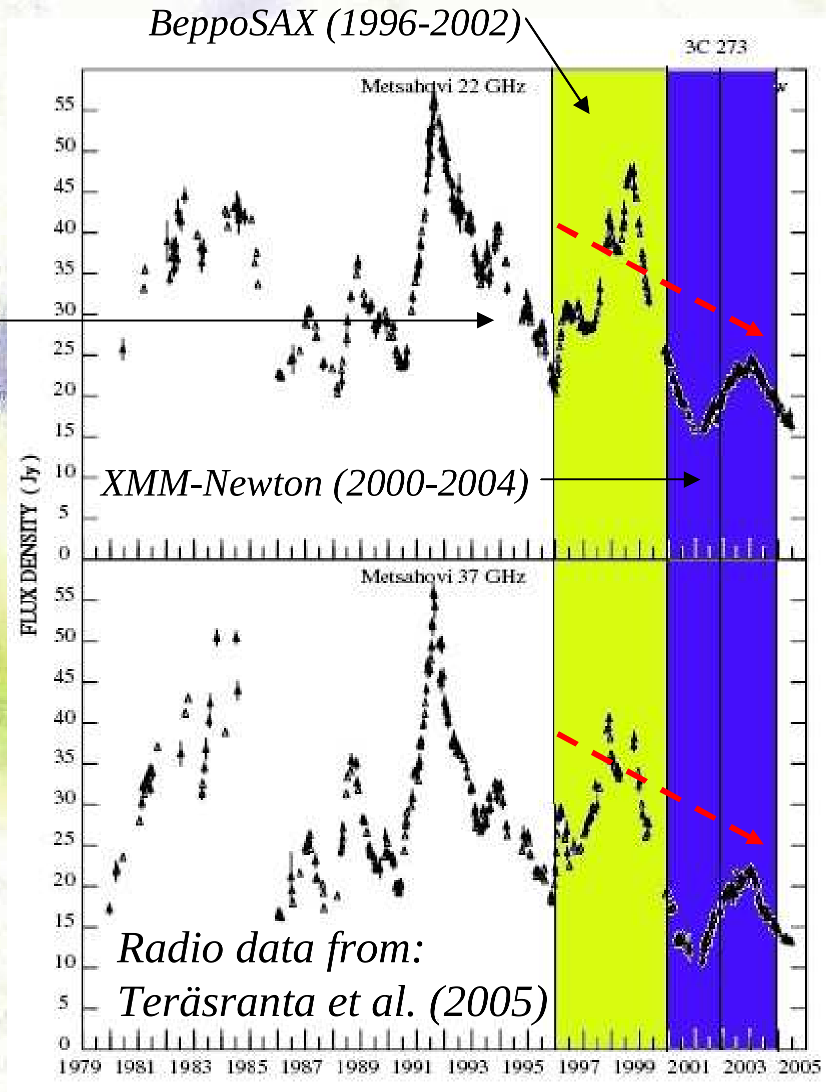
BeppoSAX vs XMM-Newton vs Radio:
increase of the average “thermal” component, indicated by an increase of the energy break in the broken power law model:

- E_{break}(*XMM-Newton*)=1.44±0.08 keV
- E_{break}(*BeppoSAX*)=0.9±0.3 keV

or – in the blackbody model – :

- kT(*XMM-Newton*)=143±6 eV
- kT(*BeppoSAX*)=54_{-4}^{+6} eV

(*BeppoSAX data from Grandi & Palumbo 2004*)



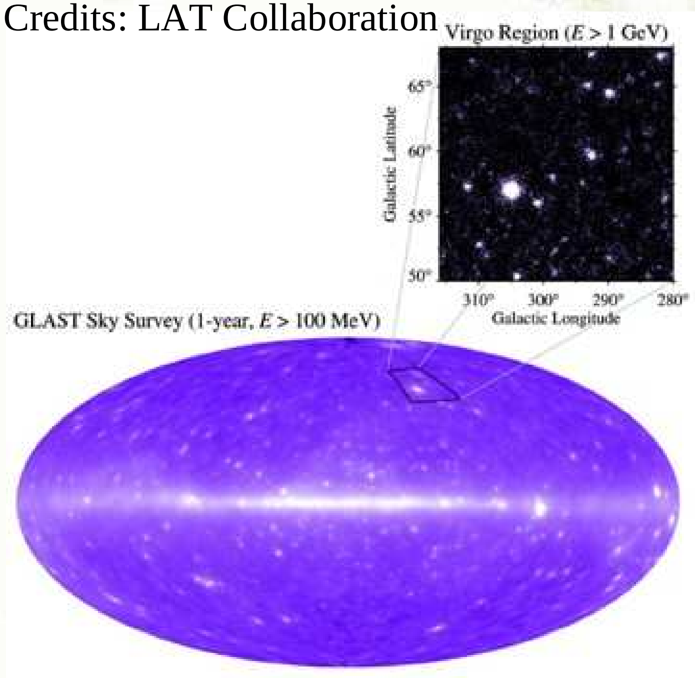
XMM-Newton data are **consistent** with (and support) the picture outlined by Grandi & Palumbo (2004).

Studies on overall properties based on public archival data
Jet viewing angle: from FSRQ to RG, with some biases…

Table 5. Parameters useful to understand γ–ray loudness. Columns: (1) Source name; (2) beaming factor δ; (3) observed flux in the 0.4 – 10 keV energy band [erg cm^{-2} s^{-1}]; (4) intrinsic luminosity in the 0.4 – 10 keV energy band [erg s^{-1}]; (5) Confidence of the EGRET detection (high > 95%; low < 95%).

Source (1)	δ (2)	F (3)	L (4)	Conf. (5)
3C 273	6.5 – 7	$\approx 10^{-10}$	$\approx 10^{46}$	high
NGC 6251	3.2 – 3.8	$\approx 10^{-12}$	$\approx 10^{43}$	low
PKS 0521 – 365	1.4 – 3	$\approx 10^{-11}$	$\approx 10^{42}$	low
Cen A	1.2 – 1.6	$\approx 10^{-10}$	$\approx 10^{41}$	high

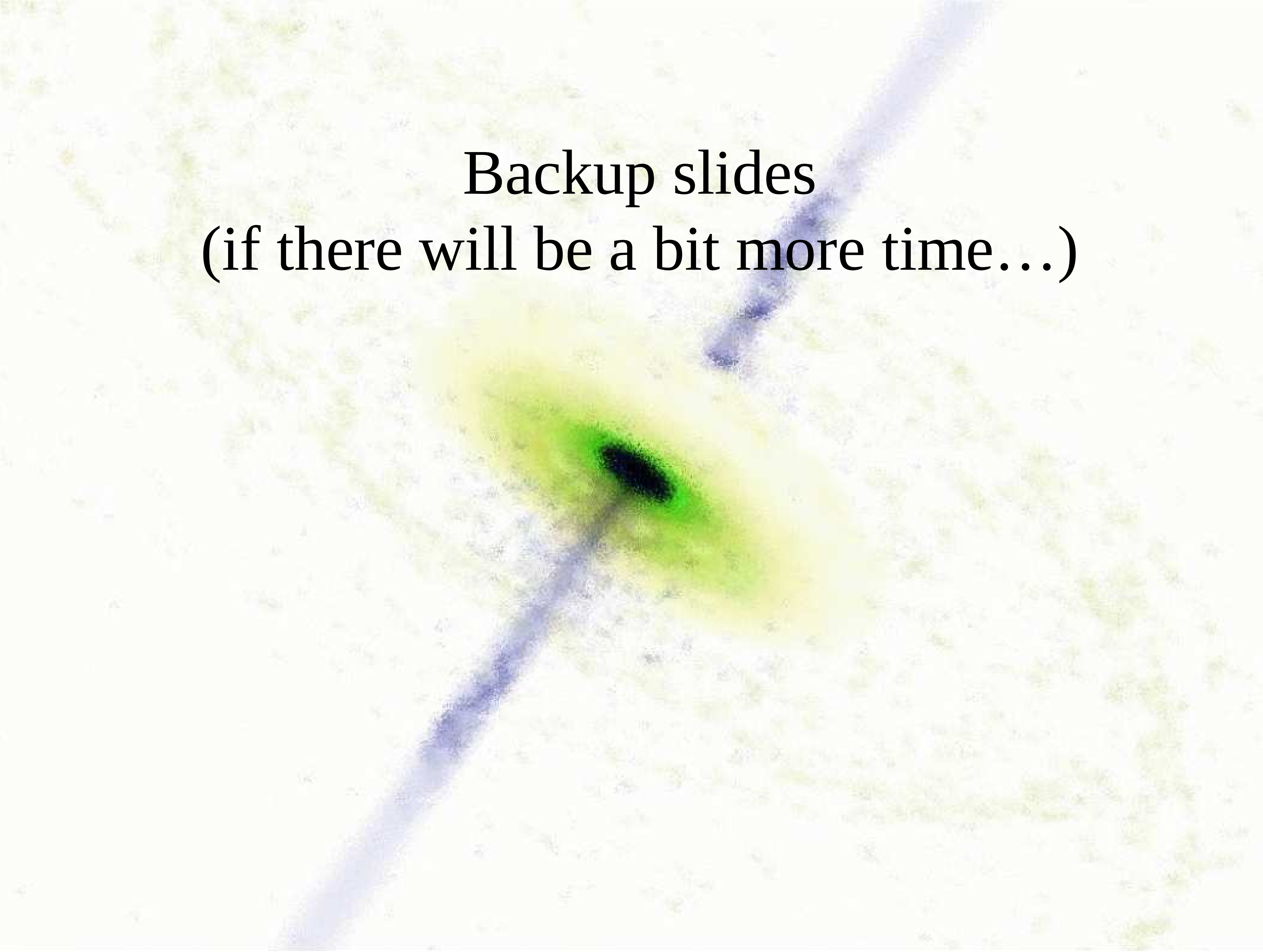
Credits: LAT Collaboration



Differences in the detection due to instrument sensitivity and distance.

Waiting for ***GLAST/Large Area Telescope*** (improvement in sensitivity of two orders of magnitudes with respect to *CGRO/EGRET*) in order to have an unbiased definition of γ-ray loudness.

Backup slides
(if there will be a bit more time…)

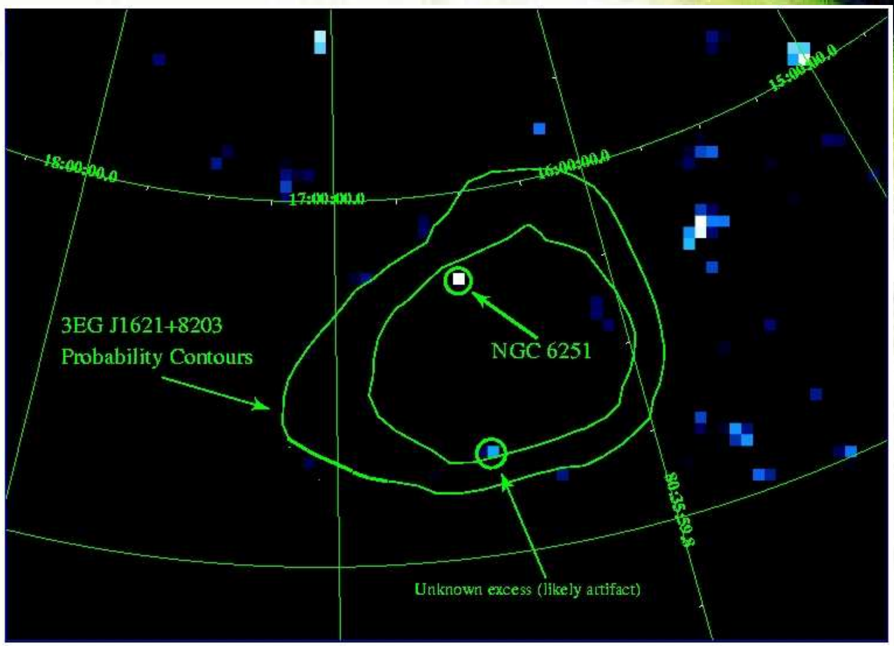


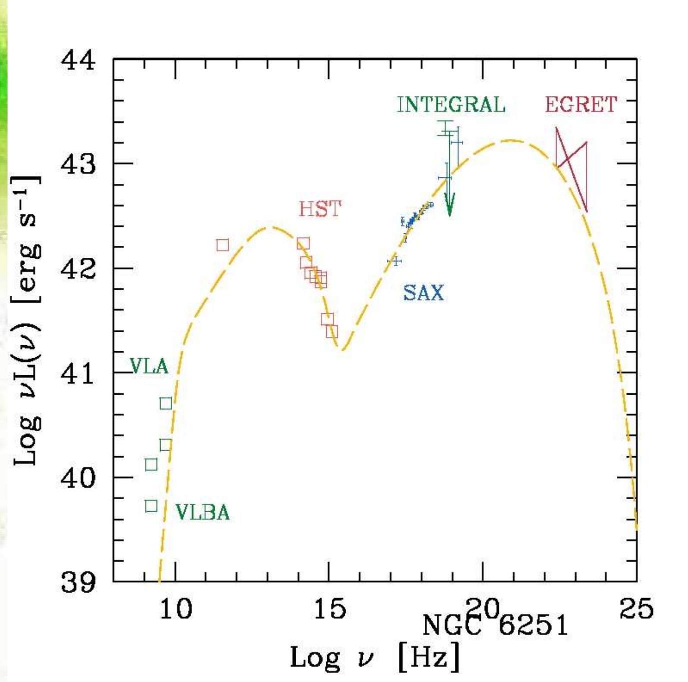
INTEGRAL AO Observations: 3EG J1621+8203 = NGC 6251

✓ Mukherjee et al. (2002, ApJ 574, 693) **first proposed** the association of 3EG J1621+8203 with the FRI radiogalaxy NGC 6251, based on X-ray (*ROSAT*, *ASCA*) observations that covered most (but not all) of the EGRET probability contours.

✓ *INTEGRAL* AO2 Observation of the **whole** EGRET probability contour (PI Foschini) revealed **only** NGC6251 inside the error contours, thus supporting the Mukherjee's findings.

✓ Faint detection (5σ) of NGC 6251, but **consistent** with the SED as modeled with a SSC.





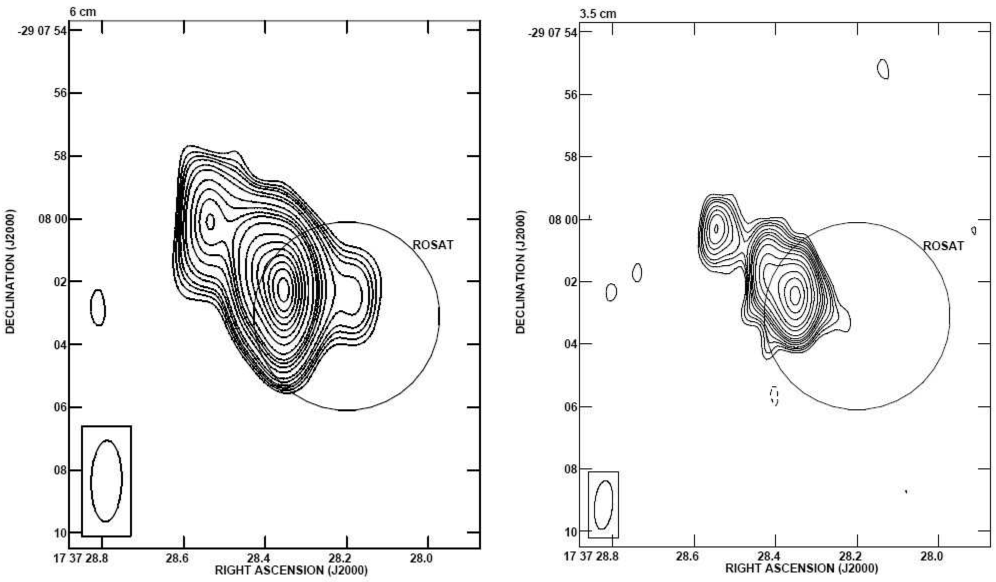
(for more details, see Foschini et al. 2005, A&A 433, 515)

INTEGRAL Core Programme: 3EG J1736-2908 = GRS 1734-292?

➢ *INTEGRAL* observations around the Galactic Centre revealed **only one** source within the probability contours of 3EG J1736-2908, that is the nearby (*z=0.0214*) AGN GRS 1734-292 (Di Cocco et al. 2004, A&A 425, 89).

➢ Originally classified as Seyfert 1, it shows a clear **bipolar jet** at radio wavelengths, with an extension of about 5″ but weak flux (23 mJy @ 5 GHz) and spectrum $S_\nu \propto \nu^{-(0.75\pm0.03)}$ (Martí et al. 1998, A&A 330, 72).

➢ **If** this association will be **confirmed** by *GLAST*, then: how is it possible that a Seyfert can generate γ-ray photons with E>100 MeV? Or is this AGN correctly classified?



NVSS Radio 6 and 3.5 cm (Martí et al. 1998)