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
✓ **First detection** of $\gamma$-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**;

✓ $\gamma$-ray loudness strongly biased by EGRET sensitivity and non-uniform exposure map; here we consider “$\gamma$-ray loud” an AGN detected by EGRET at $E>100$ MeV;
The "blazar standard model": SMBH with a relativistic jet pointed toward the observer with small angles (<10°); the relativistic motion can account for negligible \(\gamma\)-ray attenuation.

The "blazar sequence" (Fossati et al. 1998; Ghisellini et al. 1998).

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

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

0.1-300 GeV (GLAST)
0.1-30 GeV (EGRET)
≈20-200 keV (INTEGRAL)
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.)

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…

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

(credits: Tuorla Obs.)
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 \times 10^{42} \text{ erg/s in 1996}; 4 \times 10^{42} \text{ 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)
TOO activities to observe blazars in outburst: 3C 454.3
TOO with INTEGRAL (PI E. Pian)

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 \(\approx 2 \times 10^{-10} \text{ erg cm}^{-2} \text{ s}^{-1}\) 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 ≈ 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)
Studies on overall properties based on public archival data
Averages on best fits

<table>
<thead>
<tr>
<th>Name</th>
<th>$N_H$</th>
<th>$\Gamma_1$</th>
<th>$\Gamma_2$</th>
<th>$E_{\text{break}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0219 + 428</td>
<td>Gal.</td>
<td>2.91$^{+0.12}_{-0.08}$</td>
<td>2.23$^{+0.10}_{-0.09}$</td>
<td>1.3 ± 0.2</td>
</tr>
<tr>
<td>AO 0235 + 164</td>
<td>Gal.</td>
<td>2.33 ± 0.04</td>
<td>2.1 ± 0.1</td>
<td>3.3$^{+0.7}_{-0.5}$</td>
</tr>
<tr>
<td>PKS 0521 − 365</td>
<td>Gal.</td>
<td>1.95 ± 0.03</td>
<td>1.74 ± 0.03</td>
<td>1.5$^{+0.3}_{-0.2}$</td>
</tr>
<tr>
<td>S5 0716 + 714</td>
<td>Gal.</td>
<td>2.70 ± 0.02</td>
<td>1.98$^{+0.08}_{-0.09}$</td>
<td>2.3$^{+0.2}_{-0.1}$</td>
</tr>
<tr>
<td>S5 0836 + 710</td>
<td>14 ± 3</td>
<td>1.379 ± 0.007</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mkn 421</td>
<td>Gal.</td>
<td>2.38 ± 0.09</td>
<td>2.7 ± 0.2</td>
<td>2.7 ± 1.0</td>
</tr>
<tr>
<td>PKS 1127 − 145</td>
<td>122$^{+2}_{-1}$</td>
<td>1.40$^{+0.03}_{-0.05}$</td>
<td>1.22 ± 0.06</td>
<td>2.7$^{+0.8}_{-0.2}$</td>
</tr>
<tr>
<td>ON 231</td>
<td>2.5 ± 0.6</td>
<td>2.77 ± 0.04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3C 273</td>
<td>Gal.</td>
<td>2.02 ± 0.08</td>
<td>1.67 ± 0.05</td>
<td>1.44 ± 0.08</td>
</tr>
<tr>
<td>Cen A</td>
<td>1523 ± 261</td>
<td>2.22 ± 0.06</td>
<td></td>
<td></td>
</tr>
<tr>
<td>PKS 1334 − 127</td>
<td>6.7 ± 0.9</td>
<td>1.80 ± 0.04</td>
<td></td>
<td></td>
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<tr>
<td>PKS 1406 − 076</td>
<td>Gal.</td>
<td>1.59 ± 0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>NGC 6251</td>
<td>14 ± 1</td>
<td>2.11$^{+0.08}_{-0.06}$</td>
<td>1.78 ± 0.07</td>
<td>2.5$^{+0.3}_{-0.4}$</td>
</tr>
<tr>
<td>PKS 1830 − 211</td>
<td>63 ± 1</td>
<td>1.00 ± 0.09</td>
<td>1.32 ± 0.06</td>
<td>3.5 ± 0.7</td>
</tr>
<tr>
<td>PKS 2155 − 304</td>
<td>1.69 ± 0.06</td>
<td>2.9 ± 0.1</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Gal.</td>
<td>2.7 ± 0.1</td>
<td>2.94 ± 0.06</td>
<td>2.7 ± 0.7</td>
</tr>
</tbody>
</table>

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

**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:

- $E_{\text{break}}(\text{XMM-Newton}) = 1.44 \pm 0.08$ keV
- $E_{\text{break}}(\text{BeppoSAX}) = 0.9 \pm 0.3$ keV

or – in the blackbody model – :

- $kT(\text{XMM-Newton}) = 143 \pm 6$ eV
- $kT(\text{BeppoSAX}) = 54_{-4}^{+6}$ eV

*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 $\gamma$–ray loudness. Columns: (1) Source name; (2) beaming factor $\delta$; (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 $< 95\%$).

<table>
<thead>
<tr>
<th>Source</th>
<th>$\delta$</th>
<th>$F$</th>
<th>$L$</th>
<th>Conf.</th>
</tr>
</thead>
<tbody>
<tr>
<td>3C 273</td>
<td>6.5 – 7</td>
<td>$\approx 10^{-10}$</td>
<td>$\approx 10^{-46}$</td>
<td>high</td>
</tr>
<tr>
<td>NGC 6251</td>
<td>3.2 – 3.8</td>
<td>$\approx 10^{-12}$</td>
<td>$\approx 10^{43}$</td>
<td>low</td>
</tr>
<tr>
<td>PKS 0521 – 365</td>
<td>1.4 – 3</td>
<td>$\approx 10^{-11}$</td>
<td>$\approx 10^{42}$</td>
<td>low</td>
</tr>
<tr>
<td>Cen A</td>
<td>1.2 – 1.6</td>
<td>$\approx 10^{-10}$</td>
<td>$\approx 10^{41}$</td>
<td>high</td>
</tr>
</tbody>
</table>

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 $\gamma$-ray loudness.
Backup slides
(if there will be a bit more time... )
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 $S_\nu \propto \nu^{-(0.75\pm 0.03)}$ (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 $\gamma$-ray photons with $E>100$ MeV? Or is this AGN correctly classified?

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