Jets at the extremes: the GLEAM and LAT view of blazars

Marcello Giroletti - INAF Istituto di Radioastronomia
Daniele D’Antonio - Sydney University

The 2nd Pietro Baracchi Conference - Firenze - Oct 23rd, 2019
Outline

- *Fermi* & blazars at gamma rays (3LAC, 4LAC)
- MWA & blazars at low frequency (MWACS, GLEAM)
- From MWACS-3LAC (Giroletti+16) to GLEAM-4LAC (D’Antonio+19)

GLEAM-3FGL

- This slide intentionally left blank…

...#Baracchi16 was too good to do anything else!

Radio spectral properties of cores and extended regions in blazars in the MHz regime

D. d’Antonio,1* M. Giroletti,2 G. Giovannini1,2 and A. Maini1,2,3

1 Dipartimento di Fisica e Astronomia, Università di Bologna, via Gobetti 93/2, 40129 Bologna, Italy
2 INAF – IAA, via Gobetti 101, 40129 Bologna, Italy
3 Department of Physics and Astronomy, Macquarie University, Balaclava Road, North Ryde, NSW, 2109, Australia

Accepted XXX. Received YYY; in original form ZZZ

ABSTRACT

Low-frequency radio surveys allow the discovery of large numbers of unknown sources in the MHz regime. Radio frequency observations of blazar sources, such as the GaLactic and Extragalactic All-sky Surveys, are presented, for gamma-ray blazars in a low frequency (10 MHz) survey, to characterise their radio spectral properties. The results are discussed in view of observational and theoretical progress in BL Lac and quasar studies.
The Large Area Telescope (LAT) onboard Fermi

- 20 MeV - 300 GeV gamma-ray telescope launched in 2008
- 2.4 sr field of view
- PSF: $\theta_{68\%} \sim 0.8^\circ$ at 1 GeV
- operated in scanning mode, provides uniform sensitivity over whole sky in ~day time scale, ideal for
  - transients
  - MWL campaigns on single sources
  - all sky survey and population studies
- public data, available within 12 h
Evolution of *Fermi* catalogues

- longer exposure & improved analysis methods
- instrument characterisation, diffuse model, counterpart catalogues, etc.
- Each catalogue accompanied by an AGN *nLAC* catalogue
- Other catalogues focused on specific classes (pulsars, GRBs) or energy ranges
- *nFHL* catalogues useful to beat confusion

<table>
<thead>
<tr>
<th>name</th>
<th>Δt</th>
<th># src</th>
<th>% unass.</th>
<th>reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>0FGL</td>
<td>3 months</td>
<td>205</td>
<td>18%</td>
<td>Abdo et al. (2009)</td>
</tr>
<tr>
<td>1FGL</td>
<td>11 months</td>
<td>1451</td>
<td>43%</td>
<td>Abdo et al. (2010)</td>
</tr>
<tr>
<td>2FGL</td>
<td>2 years</td>
<td>1873</td>
<td>31%</td>
<td>Nolan et al. (2012)</td>
</tr>
<tr>
<td>3FGL</td>
<td>4 years</td>
<td>3033</td>
<td>33%</td>
<td>Acero et al. (2015)</td>
</tr>
<tr>
<td>4FGL</td>
<td>8 years</td>
<td>5065</td>
<td>26%</td>
<td><a href="https://arxiv.org/abs/1902.10045">https://arxiv.org/abs/1902.10045</a></td>
</tr>
</tbody>
</table>
Eight year data (4FGL-4LAC)

- Preliminary versions of 4FGL/4LAC available
  - 8 years of exposure
  - 50 MeV < E < 1 TeV
  - updated model for Galactic diffuse emission
  - 5065 sources
  - 3130 associated with blazars
  - ~50 “misaligned” AGNs

Data: https://fermi.gsfc.nasa.gov/ssc/data/access/lat/8yr_catalog/
4FGL early release: https://arxiv.org/abs/1902.10045
blazars in a nutshell

- Blazars= flat spectrum radio quasars (FSRQ) + BL Lac type objects (BLL)

- beamed counterparts of radio galaxies, dominated by emission from relativistic jets powered by accretion on SMBH
  - FSRQ: strong lines in optical spectra, prominent accretion disk signature, high radio and bolometric luminosity (FR2 counterparts), “red” SEDs
  - BLL: weak or no lines, radiatively inefficient accretion disk, low luminosity (FR1 counterparts), “blue” SEDs

- BCUs are intermediate/transitional/unconstrained blazars
γ rays and low radio frequency

- Not the best option from physical point of view but...
  - large surveys are available
  - interesting to compare blazar cores and extended regions
- MWACS=MWA commissioning survey (Hurley-Walker+15)
  - simultaneous 120, 150, 180 MHz data
  - 6100 deg², 120 mJy $5\sigma$ sensitivity, 3’ resolution
  - 14110 sources… how many (gamma-ray) blazars?
  - about 1% (and 0.5% detected by Fermi)

<table>
<thead>
<tr>
<th>3LAC sources detected in MWACS</th>
<th>Total</th>
<th>80/174</th>
<th>46%</th>
</tr>
</thead>
<tbody>
<tr>
<td>FSRQ</td>
<td>52/71</td>
<td>73%</td>
<td></td>
</tr>
<tr>
<td>BLLacs</td>
<td>19/87</td>
<td>22%</td>
<td></td>
</tr>
<tr>
<td>BCU</td>
<td>8/16</td>
<td>50%</td>
<td></td>
</tr>
</tbody>
</table>

Giroletti & MWA builders (2016)
Beyond 3LAC-MWACS: 4LAC-GLEAM

- GLEAM: wider area & deeper sensitivity
- 307455 sources (22x MWACS)
- 20 separate $\nu$-bands in 72-230 MHz range

<table>
<thead>
<tr>
<th>Class</th>
<th>3LAC-MWACS ratio</th>
<th>3LAC-MWACS det rate</th>
<th>4LAC-GLEAM ratio</th>
<th>4LAC-GLEAM det rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>total</td>
<td>87/247</td>
<td>35%</td>
<td>1274/1827</td>
<td>70%</td>
</tr>
<tr>
<td>FSRQ</td>
<td>52/71</td>
<td>73%</td>
<td>406/440</td>
<td>92%</td>
</tr>
<tr>
<td>BL Lacs</td>
<td>19/87</td>
<td>22%</td>
<td>384/659</td>
<td>58%</td>
</tr>
<tr>
<td>BCU</td>
<td>16/89</td>
<td>18%</td>
<td>456/689</td>
<td>66%</td>
</tr>
</tbody>
</table>

Hurley-Walker+17

D’Antonio+19
$S_{\text{GHz}}$ and $S_\gamma$ distributions

- Essentially all radio bright $\gamma$-blazars are detected at low-$\nu$
- $\gamma$-ray blazars can have also rather faint $S_{\text{GHz}}$ - on which GLEAM can tell little
- some intermediate $S_{\text{GHz}}$ $\gamma$-blazars likely missing in GLEAM because of an inverted spectrum (but effect now alleviated in comparison to MWACS)
- In $\gamma$ rays, the detection rate decreases progressively but still not negligible even for the faintest blazars
Spectral properties

- blazars are significantly flatter than the average GLEAM source
- entire GLEAM: \( \langle \alpha_{\text{low}} \rangle = 0.77 \pm 0.01 \)
- γ-ray blazars (GLEAM): \( \langle \alpha_{\text{low}} \rangle = 0.44 \pm 0.01 \)
- γ-ray blazars (MWACS): \( \langle \alpha_{\text{low}} \rangle = 0.50 \pm 0.09 \)
- beamed cores remain important at low-ν

\[ S_\nu \propto \nu^{-\alpha} \]

\( D'\text{Antonio+19} \)

\( \alpha_{\text{low}} \) distribution
- all GLEAM
- GLEAM γ-ray blazars
$S_{\text{low}} - S_Y$ “correlation”

- broad trend of connection between $S_{\text{GLEAM}}$ and 4FGL energy flux
  - 652 sources, $r=0.27$, chance $p=10^{-6}$
- Significant improvement thanks to increased size sample; MWACS had:
  - 82 sources, $r=0.27$, chance $p=0.06$
- Still much more scattered than when using cm-λ data:
  - un-beamed lobes become important at low-$\nu$

D’Antonio+19
What about the small scales?

- More and more **all-sky** monitors (*Fermi*, GW, IC, …)
- Most SKA precursors in Southern hemisphere
- North-South long baseline critical for many science cases
- Australian and African VLBI dishes crucial to high resolution for SKA1 (both MID and LOW)

Structured relativistic jets formed after BNS merger (*Ghirlanda et al. 2019, Science*)

**EVN+LBA+VLBA**

**EVN+LBA e-VLBI observations of the first γ-NLSy1**

Take home messages

1. *Fermi* (and CTA) provide **all-sky** survey for **energetic universe** (over 5000 sources, 3100 blazars and counting)

2. Synergy with **low frequency** fundamental to classify and understand sources

3. ITA-AUS should work together on this - including VLBI