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

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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

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…#Baracchi16 was too good to do anything else!

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

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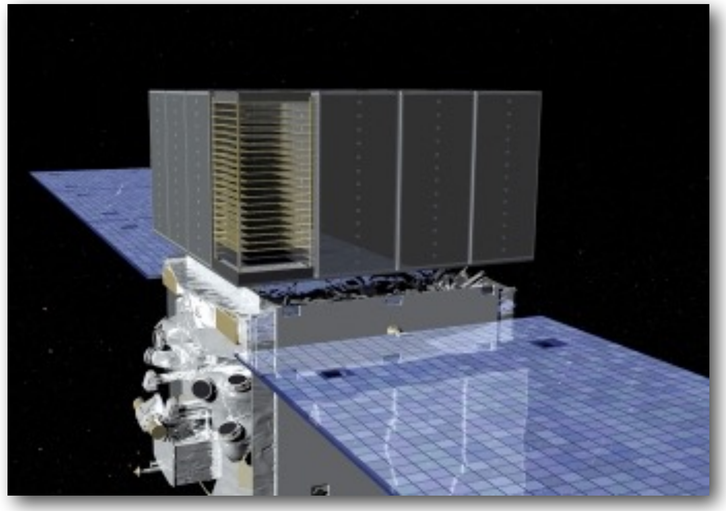
ABSTRACT
Low-frequency radio surveys allow … of sources previously known and char… radio frequency observations of bl… s, such as the GaLactic and Extraga… ch for gamma-ray blazars in a low frequency ($\nu < 240$ MHz) survey, to characterise the

D'Antonio et al. MNRAS accepted arXiv:1910.08235

The Large Area Telescope (LAT) onboard *Fermi*

- 20 MeV - 300 GeV gamma-ray telescope launched in 2008
- 2.4 sr field of view
- PSF: $\theta_{68\%}$~0.8° 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
  - <u>all sky survey and population studies</u>
- public data, available within 12 h



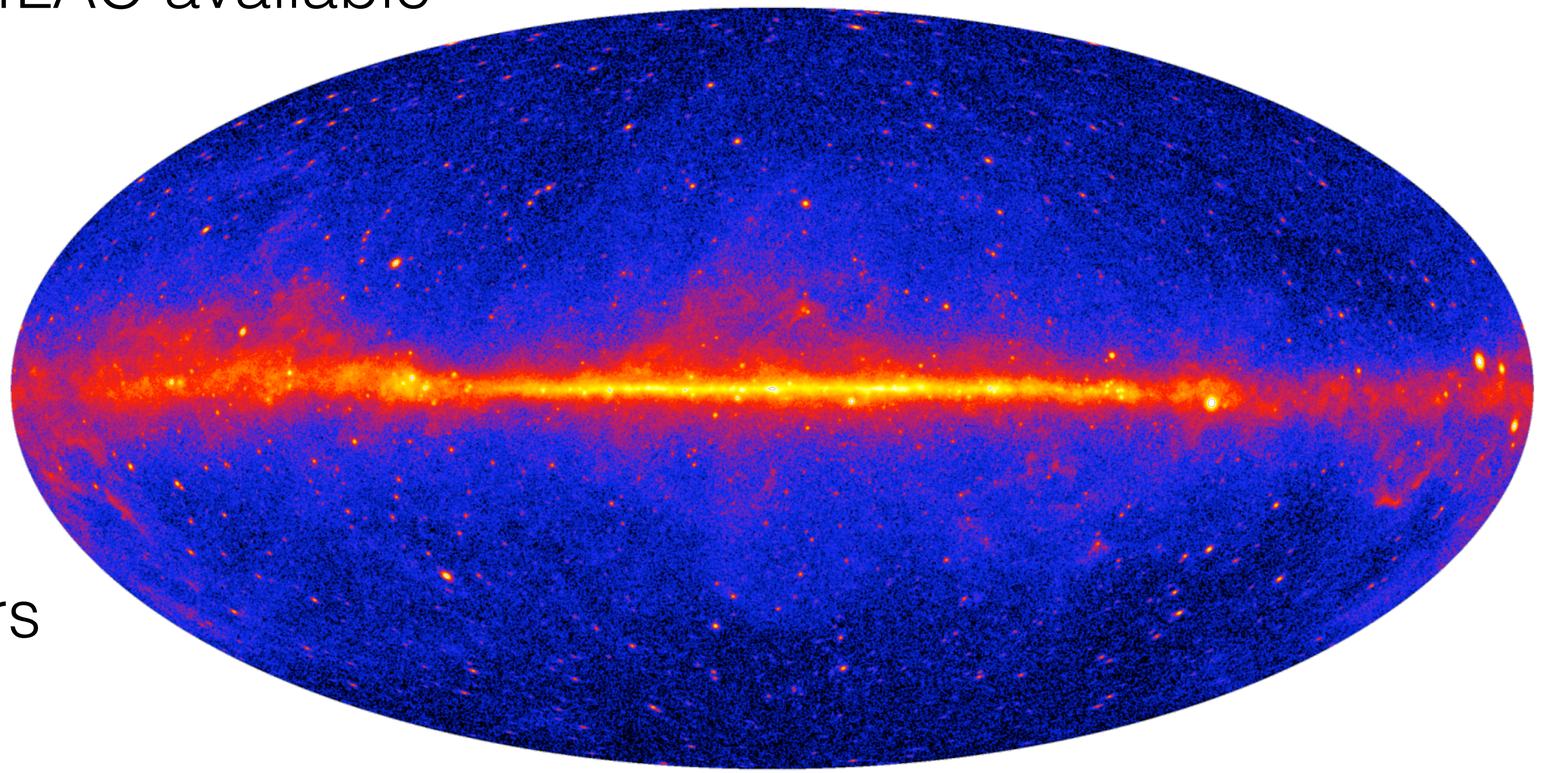
Evolution of *Fermi* catalogues

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

name	**Δt**	**# src**	**% unass.**	**reference**
0FGL	3 months	205	18%	Abdo et al. (2009)
1FGL	11 months	1451	43%	Abdo et al. (2010)
2FGL	2 years	1873	31%	Nolan et al. (2012)
3FGL	4 years	3033	33%	Acero et al. (2015)
4FGL	*8 years*	*5065*	*26%*	*https://arxiv.org/abs/1902.10045*

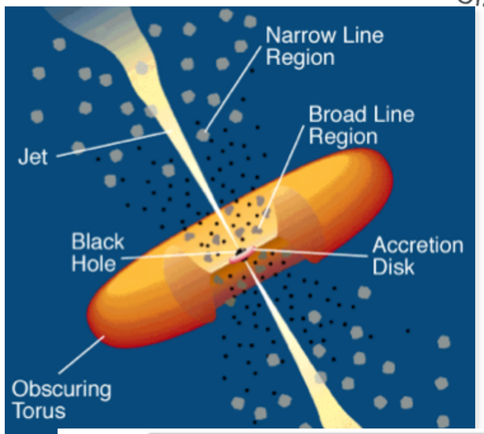
Eight year data (4FGL-4LAC)

- 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

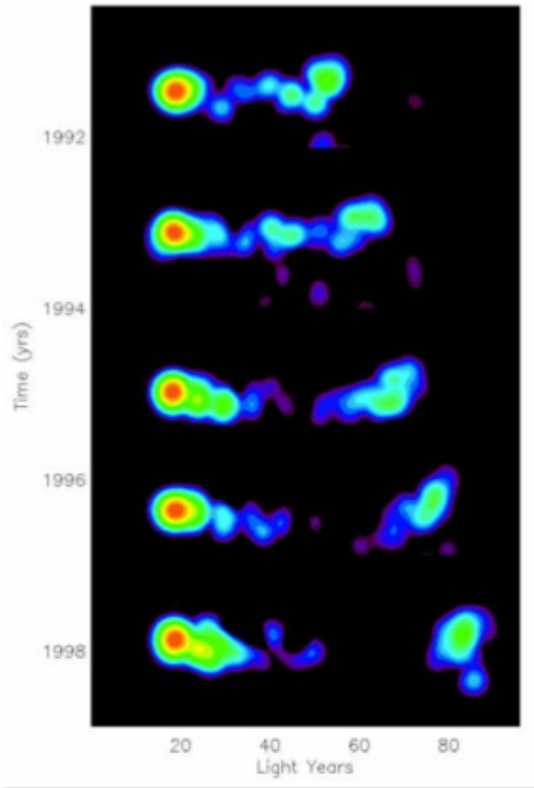


data: https://fermi.gsfc.nasa.gov/ssc/data/access/lat/8yr_catalog/
4FGL early release: https://arxiv.org/abs/1902.10045
4LAC early release: https://arxiv.org/abs/1905.10771

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

Giroletti & MWA builders (2016)

- MWACS=MWA commissioning survey (Hurley-Walker+15)
- simultaneous 120, 150, 180 MHz data
- 6100 deg^2,120 mJy 5σ sensitivity, 3’ resolution
- 14110 sources… how many (gamma-ray) blazars?
- about 1% (and 0.5% detected by Fermi)

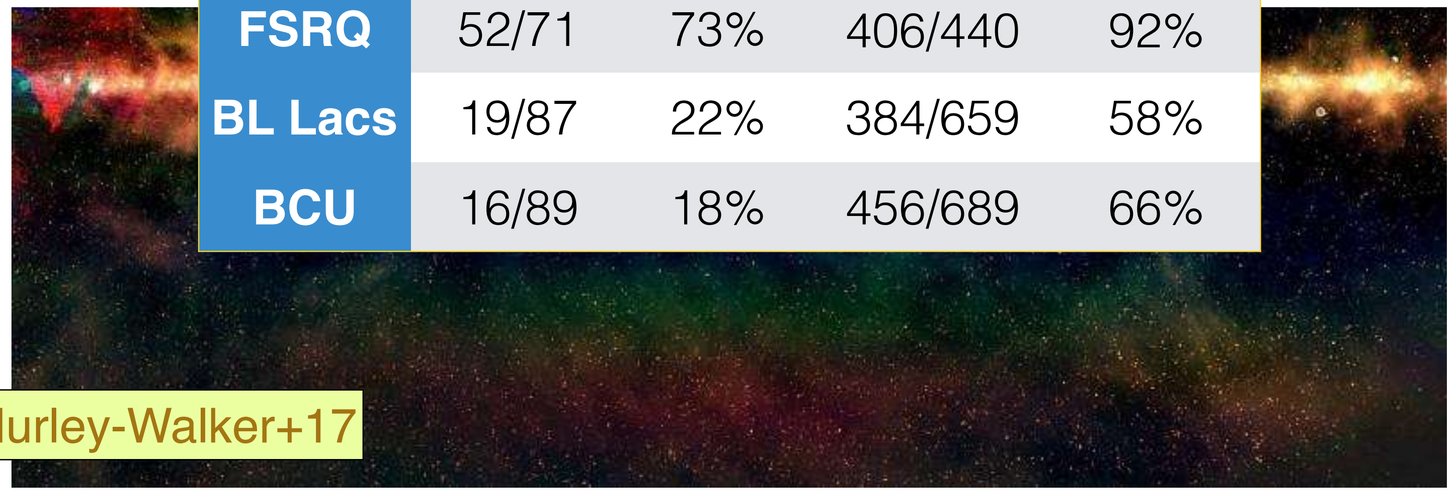
3LAC sources detected in MWACS

Total	**80/174**	**46%**
FSRQ	**52/71**	**73%**
BLLacs	**19/87**	**22%**
BCU	**8/16**	**50%**

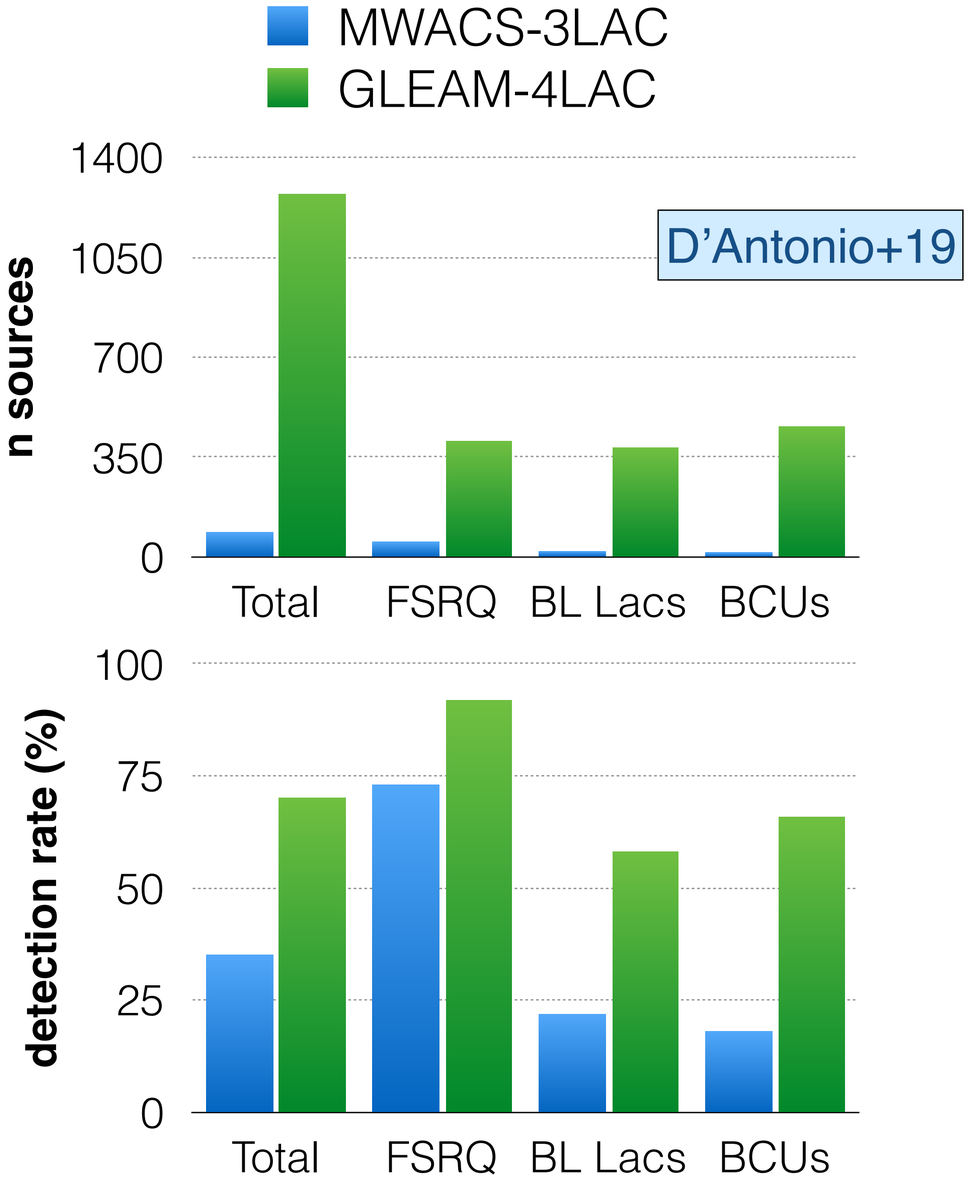
Beyond 3LAC-MWACS: 4LAC-GLEAM

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

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

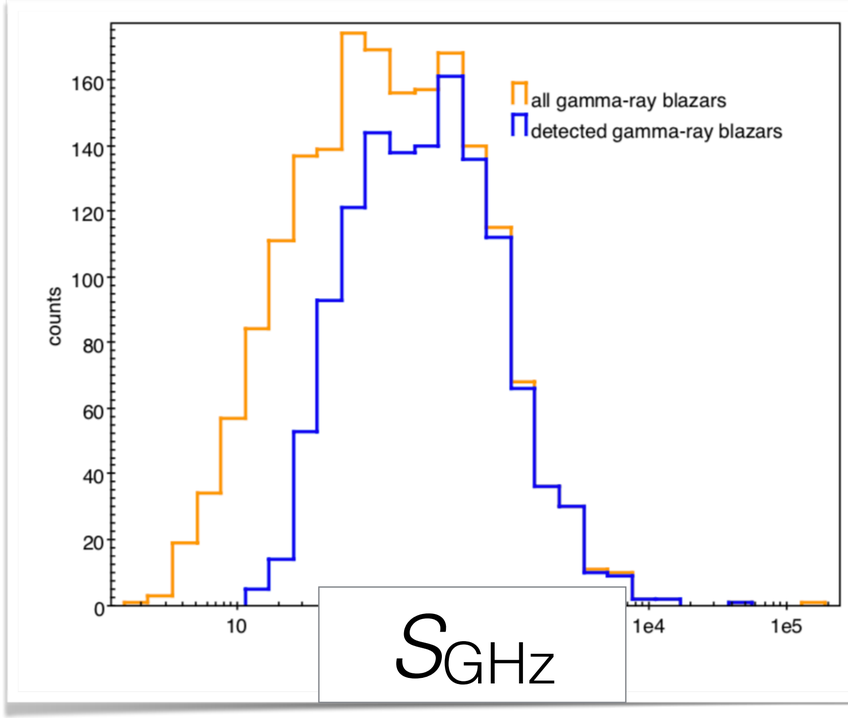


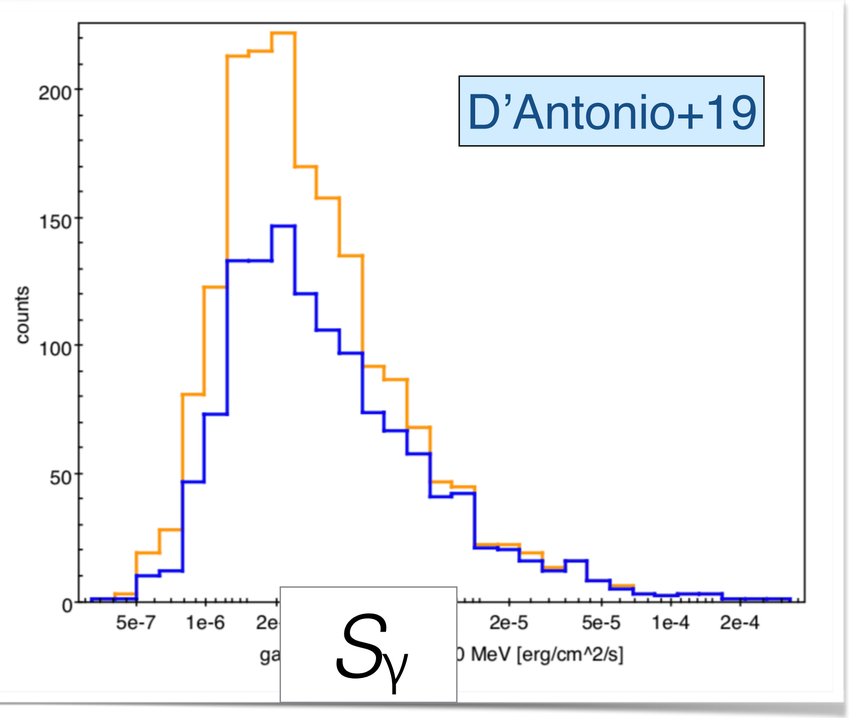
Hurley-Walker+17



S_{GHz} and S_γ distributions

- Essentially all radio bright γ-blazars are detected at low-ν
- γ-ray blazars can have also rather faint S_{GHz} - on which GLEAM can tell little



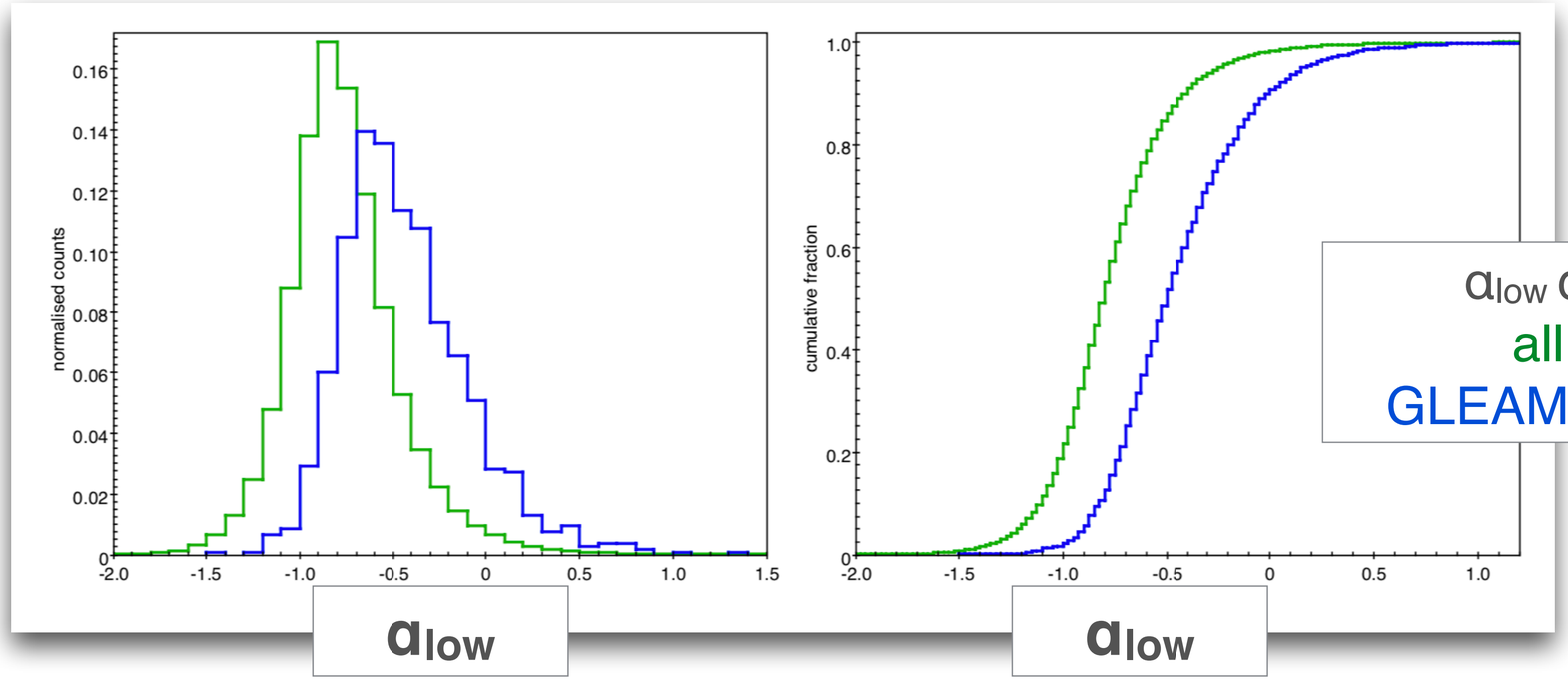


- some intermediate S_{GHz} γ-blazars likely missing in GLEAM because of an inverted spectrum (but effect now alleviated in comparison to MWACS)
- In γ rays, the detection rate decreases progressively but still not negligible even for the faintest blazars

Spectral properties

$$S_\nu \propto \nu^{-\alpha}$$

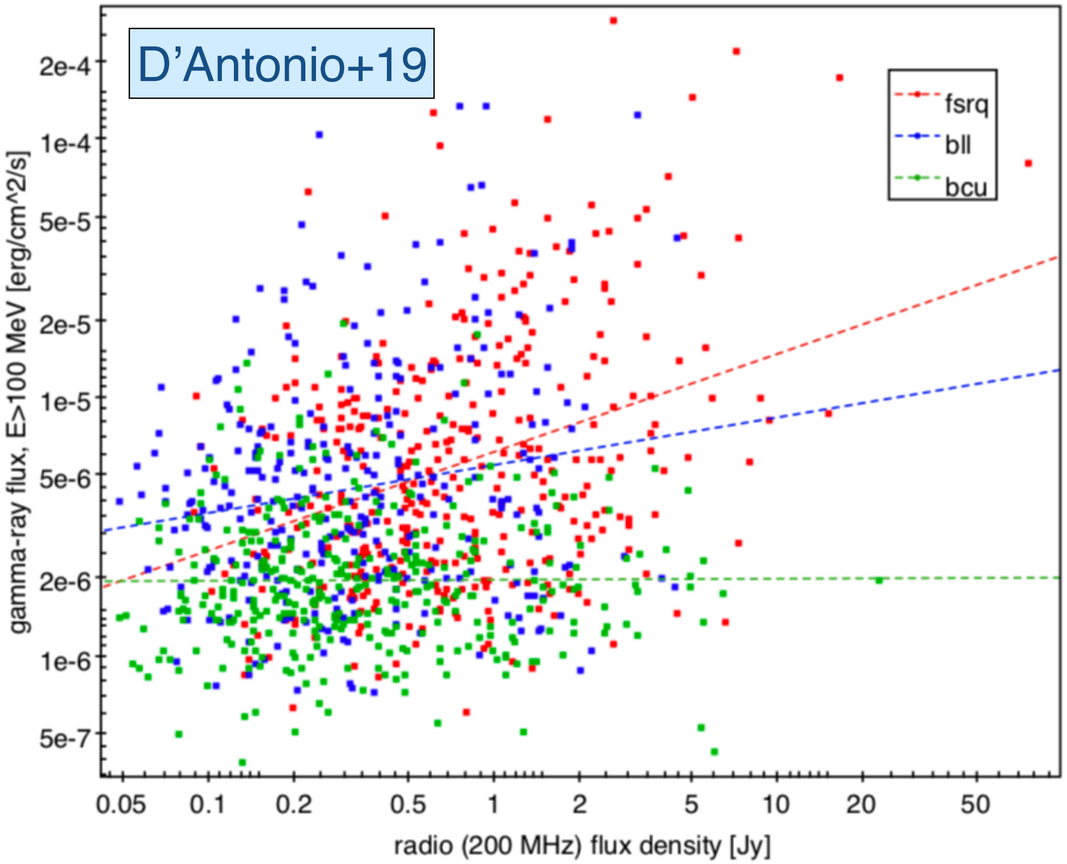
D'Antonio+19



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

S_{low} - S_{γ} "correlation"

- broad trend of connection between S_{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-ν*

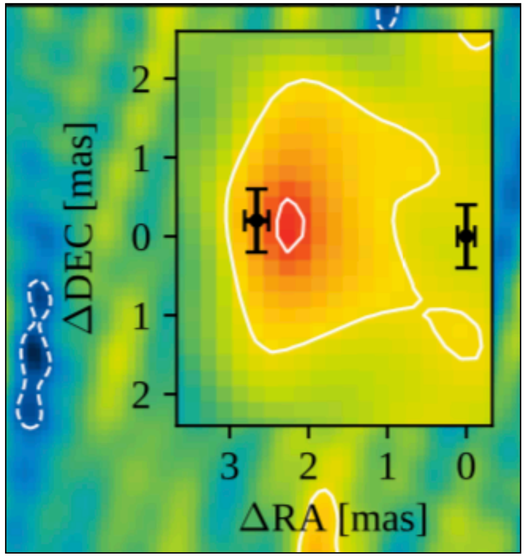


What about the small scales?

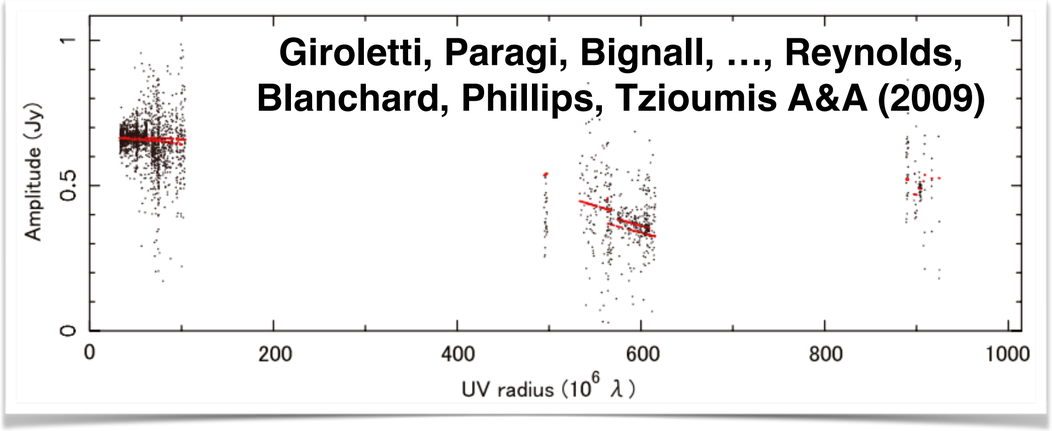
- More and more ***all-sky*** monitors (*Fermi*, GW, IC, …)
- Most SKA precursors in Southern hemisphere
- North-South long baseline critical for many science cases
- Australian and African VLBI dishes crucial to high resolution for SKA1 (both MID and LOW)

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*

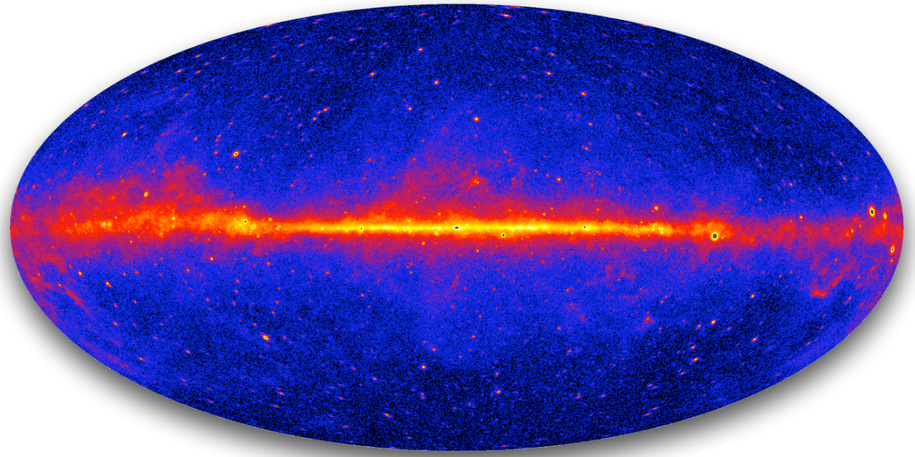


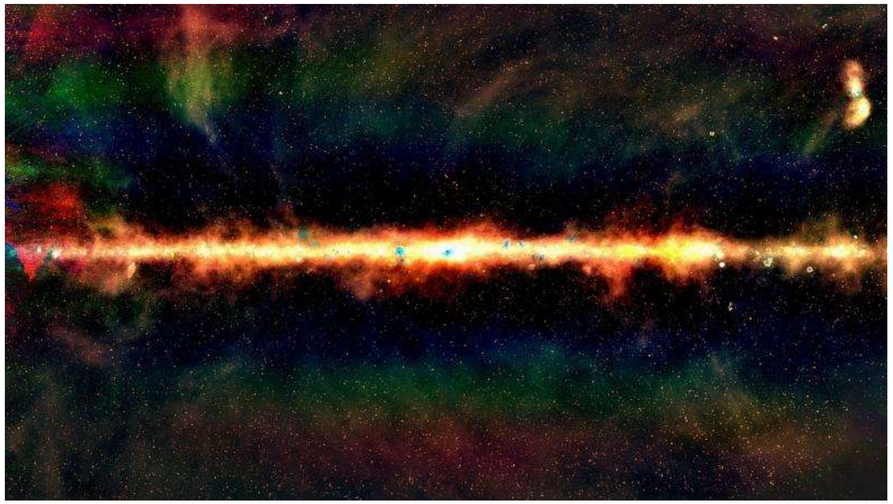
Take home messages

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**





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