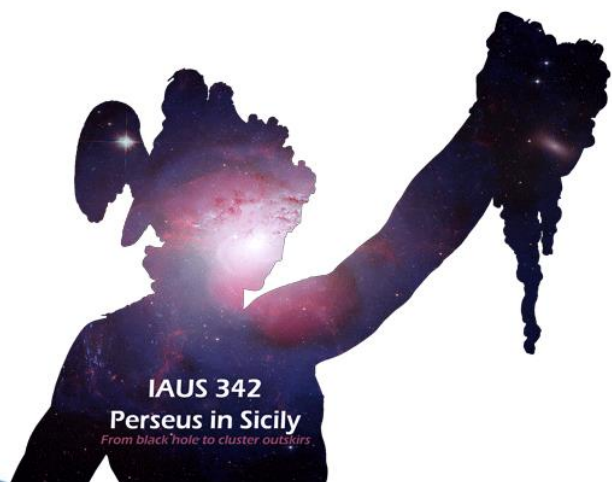# Exploring the radio and GeV-TeV γ-ray connection in the different blazar sub-classes

Presented by:

Rocco Lico,

M.Giroletti, M.Orienti, L. Costamante, V.Pavlidou, F.D'Ammando, F. Tavecchio, G.Giovannini, et al.
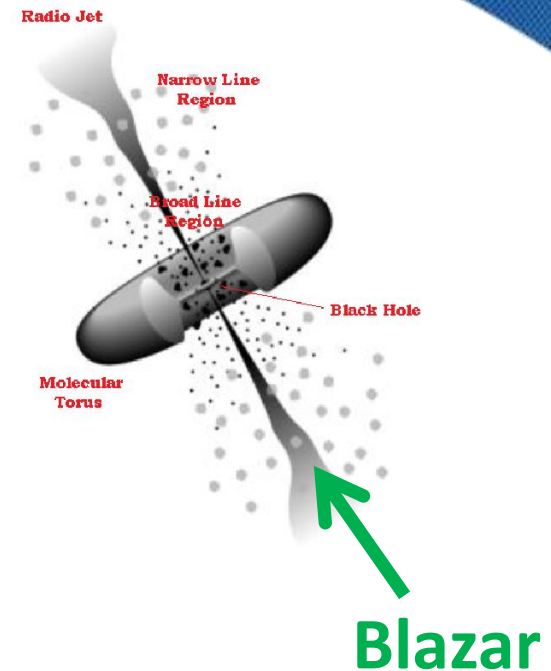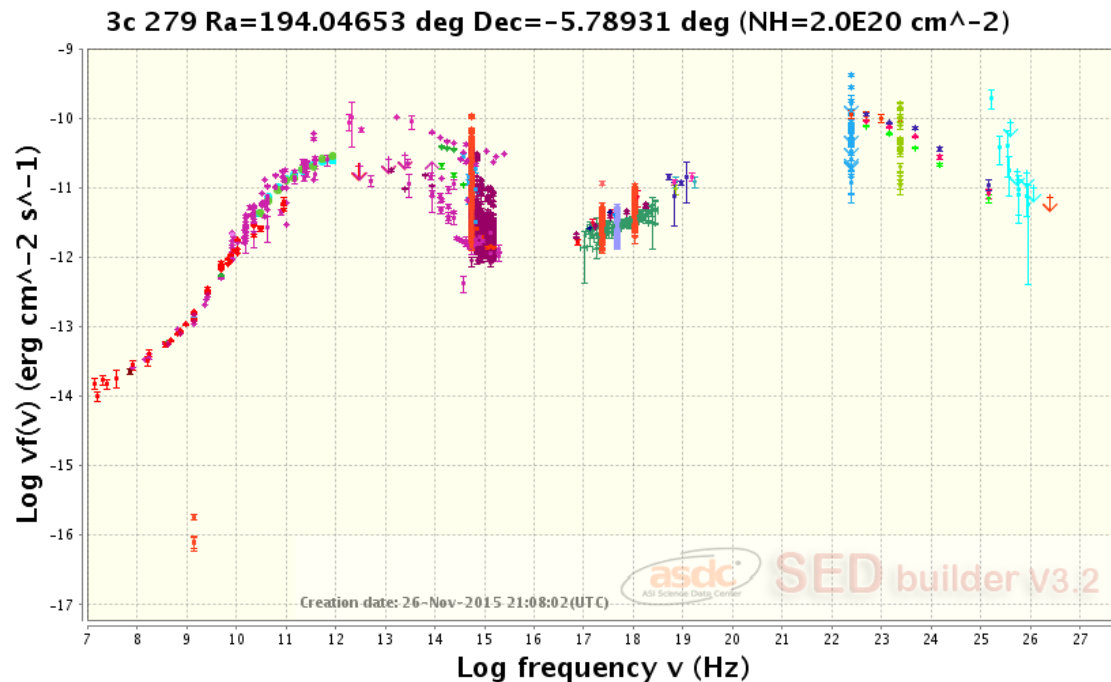
IAUS 342
Perseus in Sicily
From black hole to cluster outskirts

Spectral energy distribution (SED)

3c 279 Ra=194.04653 deg Dec=-5.78931 deg (NH=2.0E20 cm^-2)

Blazar

Blazar SED: two non-thermal components from radio to γ rays:

❑ LE component -> synchrotron emission from relativistic e^- in the jet.
❑ HE component -> inverse Compton from relativistic e^- in the jet with surrounding LE photons:

➢ same synchrotron photons (Synchrotron Self Compton model, **SCC**);
➢ external photons (e.g. from accretion disk, BLR, dusty torus) (External Compton model, **EC**).

Blazar spectral sub-classes

Fossati et al. (1998)
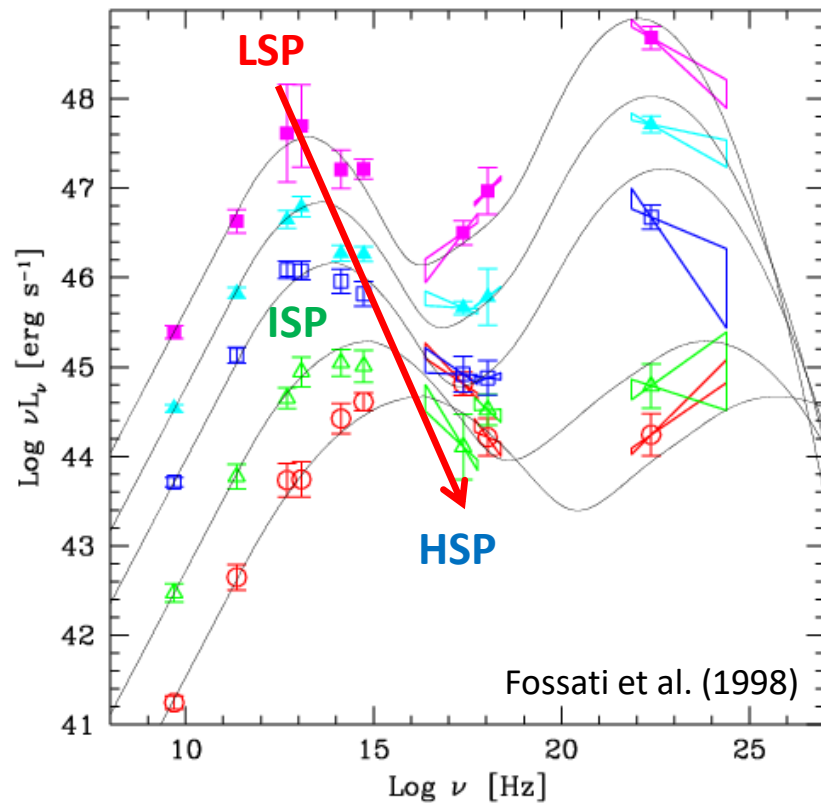
✓ Low synchrotron peaked **LSP**
$\nu_{s,peak} < 10^{14}$ Hz.

✓ Intermediate synchrotron peaked **ISP**
10^{14} Hz $< \nu_{s,peak} < 10^{15}$ Hz.

✓ High synchrotron peaked **HSP**
$\nu_{s,peak} > 10^{15}$ Hz.

The peak frequencies of the LE and HE components correlate:
- When the radio/total power increases, both LE and HE peaks shift to lower frequencies.
- Luminosity ratio between HE and LE peaks (Compton dominance) increases with L_{bol}.

Radio and γ-ray emission connection

The *Fermi*-LAT revealed that blazars dominate the census of the γ-ray sky

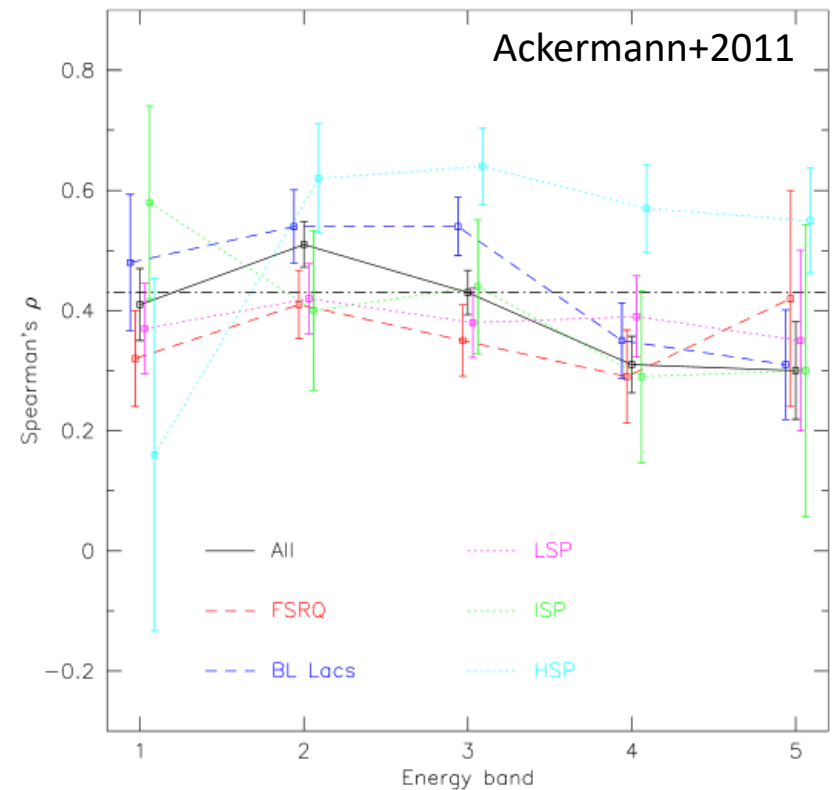## Is there any correlation between radio and γ-ray emission?

- Emission models (e.g. SSC, EC), γ-ray emission region, EBL attenuation, Blazar sequence.

Orienti Talk for more details

Ackermann et al. 2011:
strong (*r=0.46*) and **significant** (*p=9 x 10⁻⁸*) correlation between radio and **100 MeV - 100 GeV** γ-ray emission.

- 1FGL AGNs.
- Archival (8 GHz) and concurrent (15GHz) obs. (OVRO).
- Statistical significance with Pavlidou+2012 method.

Ackermann+2011

The correlation strength depends on:
simultaneity, blazar type and **energy band** → weaker correlation at higher γ-ray energies
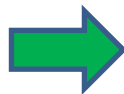
Radio and VHE emission connection

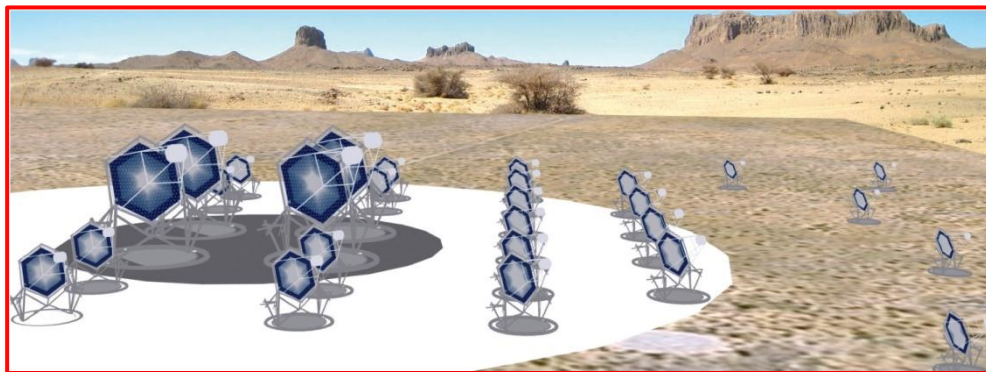## Is there any correlation between radio and VHE γ-rays?

At present elusive due to the lack of a homogeneous coverage of the VHE sky

Imaging atmospheric Cherenkov telescopes:

- Pointing mode obs.
- Limited field of view.
- Limited observing time.
- Sources in a peculiar state.

VHE catalogs strongly biased

1FHL *Fermi* catalog

1FHL - First *Fermi*-LAT catalog of sources above 10 GeV (Aug 2008 - Aug 2011).

Why 1FHL?

Large, deep and unbiased sample in the energy range **10-500 GeV**.

- Connection between radio and VHE emission.
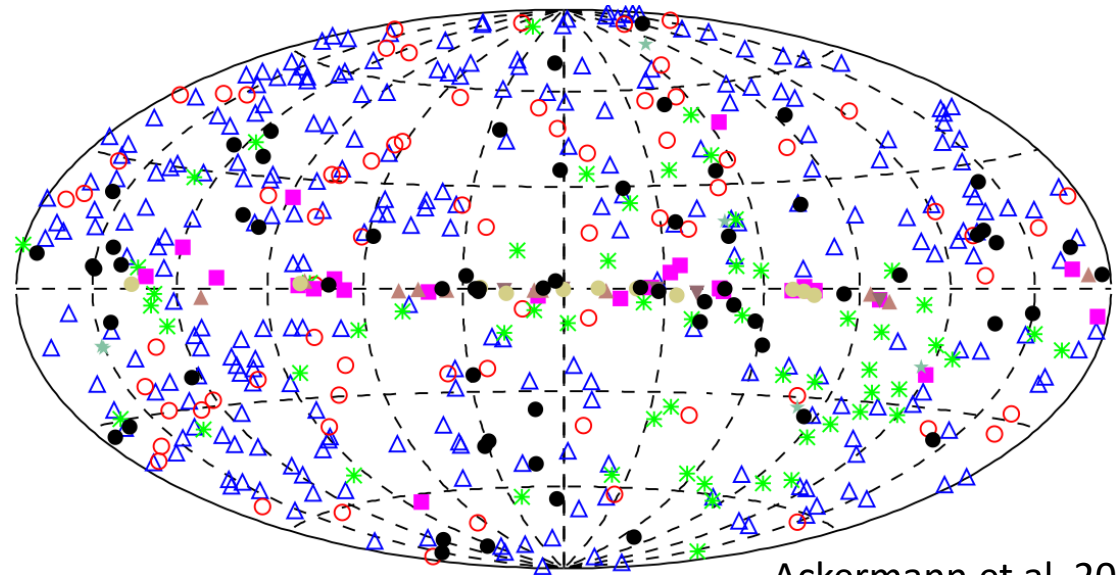- Characterization of the most extreme γ-ray sources.

393/514 (76%) ──→ AGNs

330/393 (84%) ──→ Blazars

Ackermann et al. 2013

Blazars dominate the γ-ray sky at E>10 GeV

△ BL Lac	○ FSRQ	* AGNs of unknown type
■ PSR	▲ SNR	▼ PWN
● Other Galactic objects	★ Other (non-beamed) Extragalactic objects	● No association

Correlation analysis: scatter plots

237 1FHL sources

3FGL (0.1-300 GeV)

1FHL (10-500 GeV)
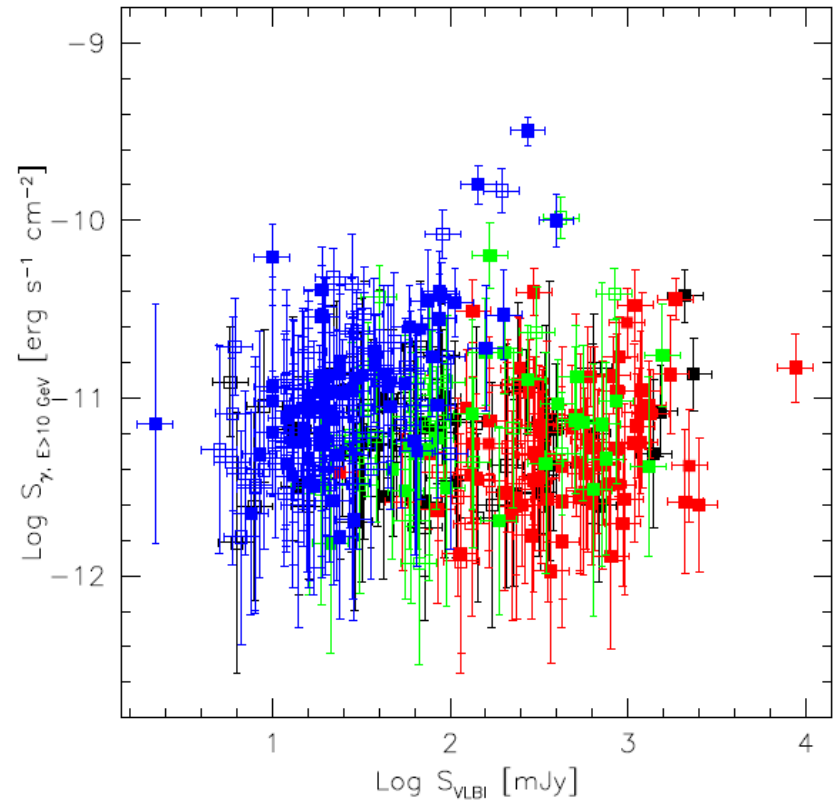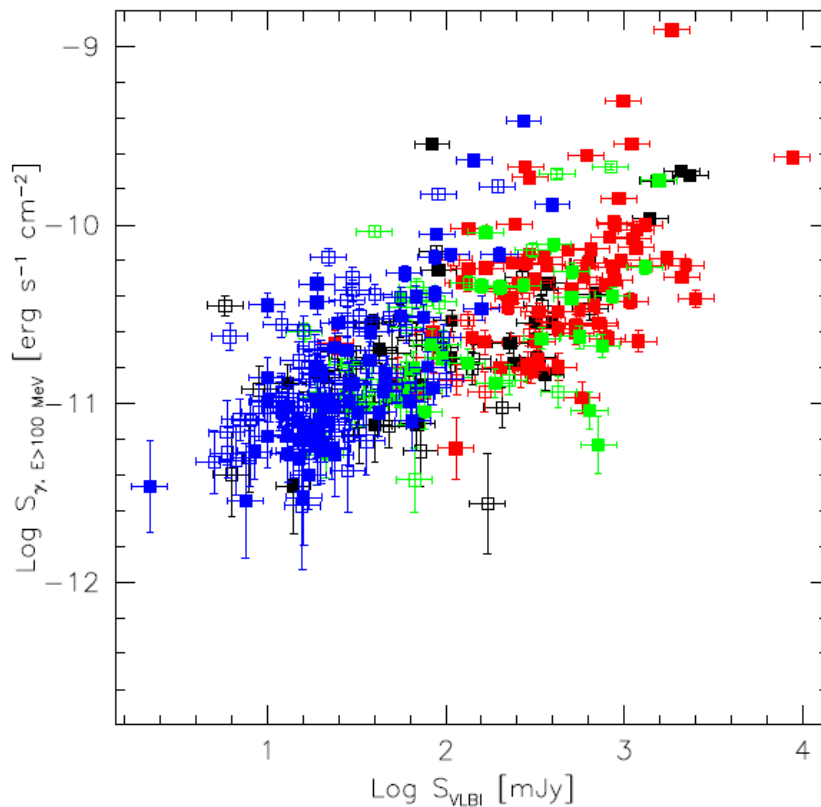
LSP -> **red** squares, ISP -> **green** squares, HSP -> **blue** squares

Statistical significance -> method based on permutations of measured quantities (Pavlidou+2012):

✓ same lum. dynamical range and properties as the original sample;

✓ observational biases and distance effects.

Correlation analysis: results

Source type	Catalog	Number of sources	Number of z-bins	r-Pearson	Significance
All sources	1FHL	147	14	-0.05	0.59
	3FGL	147	14	0.71	$< 10^{-6}$
BL Lac	1FHL	100	9	0.12	0.55
	3FGL	100	9	0.70	$< 10^{-6}$
FSRQ	1FHL	44	4	-0.01	0.99
	3FGL	44	4	0.49	$< 10^{-6}$
HSP	1FHL	60	5	0.57	1.0×10^{-6}
	3FGL	60	5	0.77	$< 10^{-6}$
ISP	1FHL	23	2	0.19	0.40
	3FGL	23	2	0.46	2.5×10^{-2}
LSP	1FHL	52	5	0.21	0.12
	3FGL	52	5	0.43	3.0×10^{-6}

Radio VLBI vs. hard γ-ray emission (1FHL):

➤ No evidence for a correlation (full sample, FSRQs, BL Lacs, LSP, ISP).
➤ Strong and significant correlation for **HSP objects**.

Radio VLBI vs. soft γ-ray emission (3FGL):

➤ Strong and significant correlation for all sub-classes.
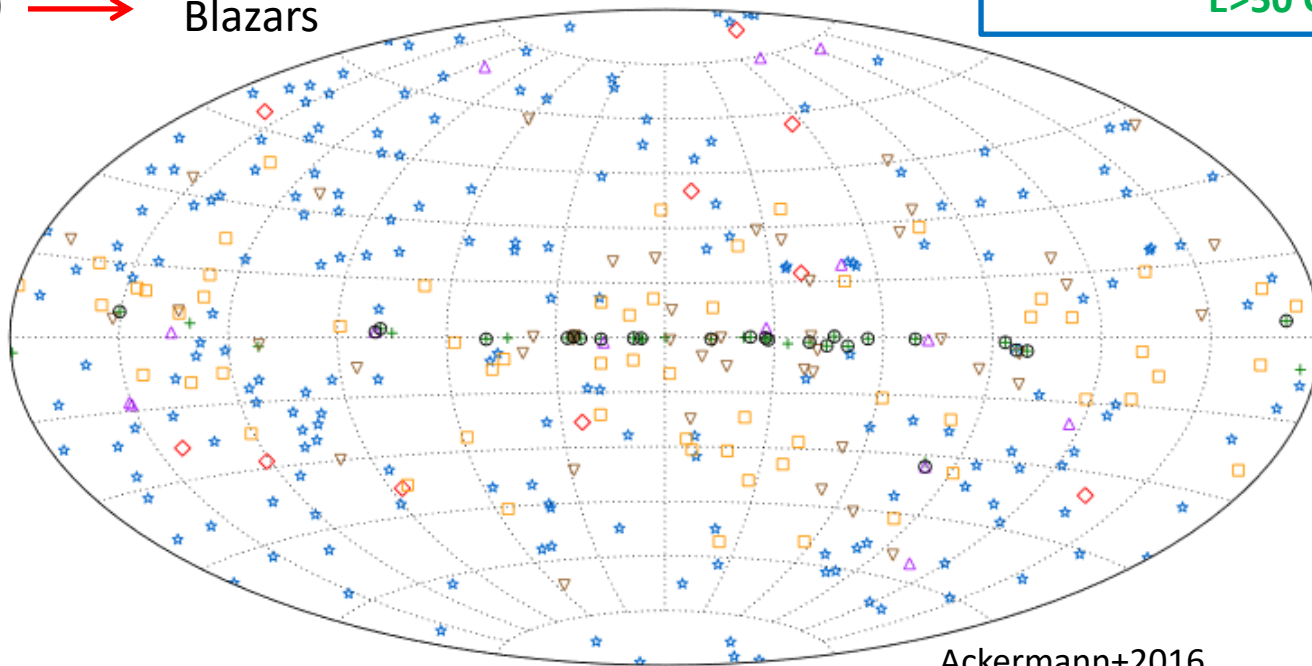
2FHL *Fermi* catalog

2FHL - Second *Fermi*-LAT catalog of HE sources above 50 GeV (Aug 2008 - Apr 2015).

360 sources detected in the energy range **50 GeV - 2 TeV**.

271/360 (75%) ⟶ AGNs

265/271 (98%) ⟶ Blazars

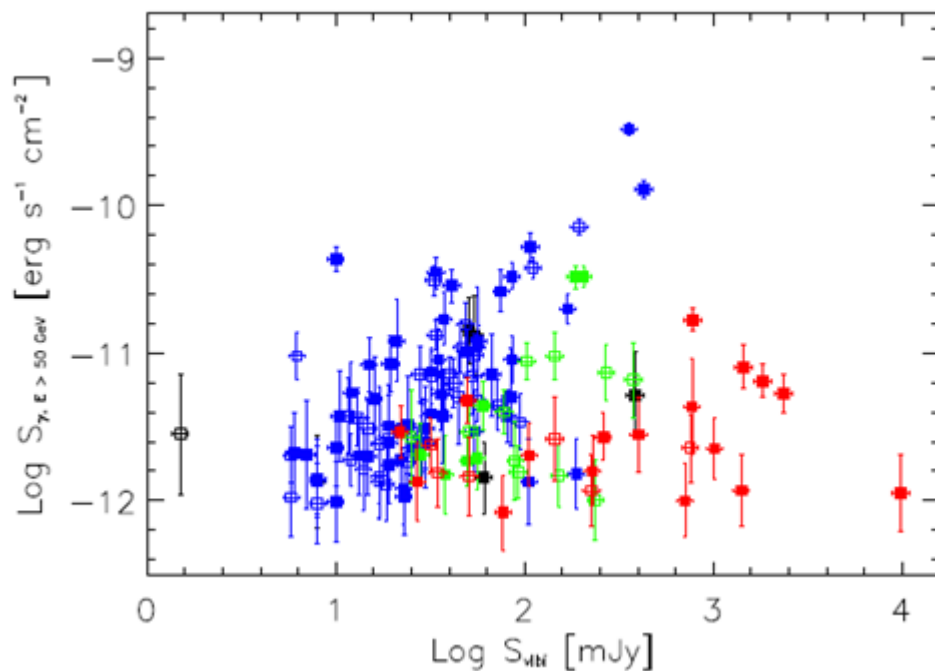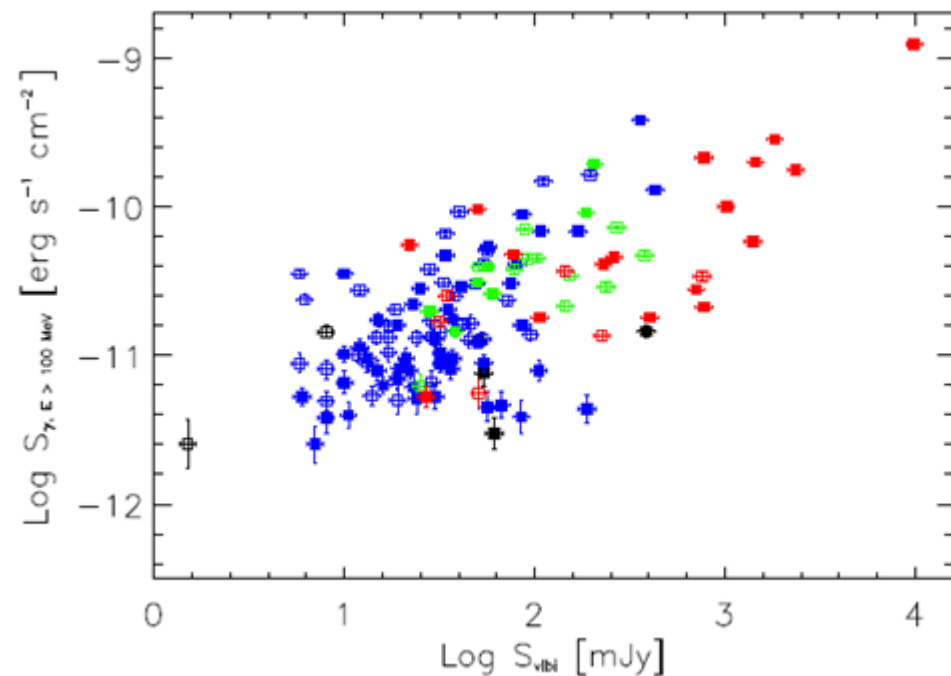> **Blazars dominate the γ-ray sky at E>50 GeV**

Ackermann+2016

+ SNRs and PWNe	★ BL Lacs	◻ Unc. Blazars	▽ Unassociated
× Pulsars	◇ FSRQs	△ Others	○ Extended

2FHL: scatter plots

131 sources

3FGL (0.1 - 300 GeV)

2FHL (50 GeV -2 TeV)

LSP -> **red** squares, ISP -> **green** squares, HSP -> **blue** squares

2FHL Correlation analysis: results

Source type	Catalog	Number of sources	Number of z-bins	r-Pearson	Significance
All sources	2FHL	76	7	0.13	0.36
	3FGL	76	7	0.72	$< 10^{-6}$
BL Lac	2FHL	63	6	0.23	0.34
	3FGL	63	6	0.73	$< 10^{-6}$
HSP - with z	2FHL	48	4	0.57	7.0×10^{-6}
	3FGL	48	4	0.58	$< 10^{-6}$

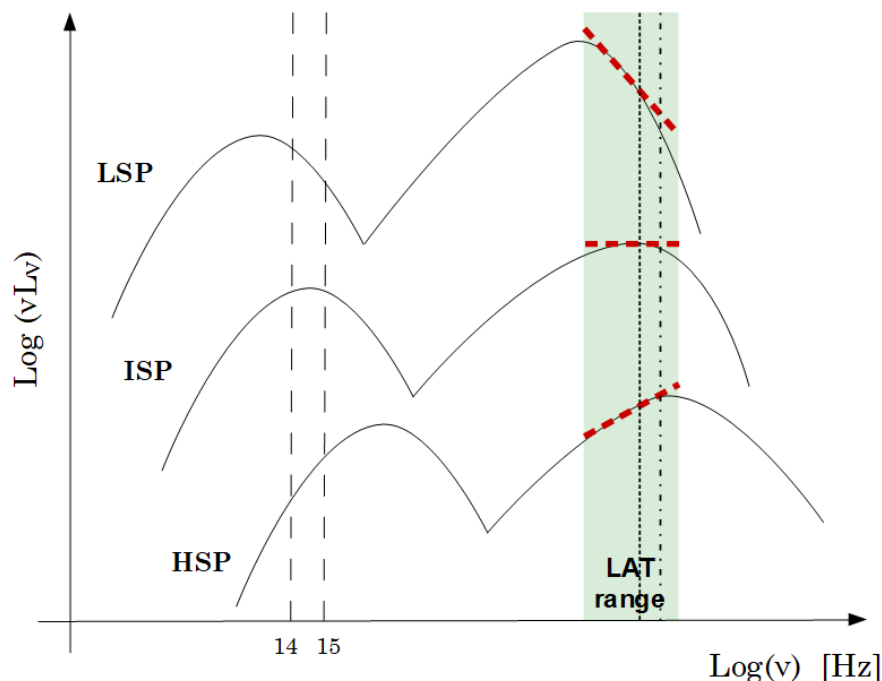**Including HSP objects without know redshift**

Radio VLBI vs. soft γ-ray emission (3FGL):

➤ Strong and significant correlation for all sub-classes.

Radio VLBI vs. hard γ-ray emission (1FHL):

➤ No evidence for a correlation (full sample and BL Lacs).
➤ Strong and significant correlation for **HSP objects** (See also Piner & Edwards 2014).

Correlation analysis: discussion

Powerful objects (i.e. FSRQs and BL Lacs of the LSP type):
- soft γ-ray spectra -> HE component peaks at energies lower than those sampled by LAT;
- severe cooling losses of the emitting particles.

Weak objects (i.e. HSP objects):
- Energy losses less severe -> HE peak which is above ~100 GeV.
- The part of the HE spectrum affected by cooling effects is beyond the LAT energy range;
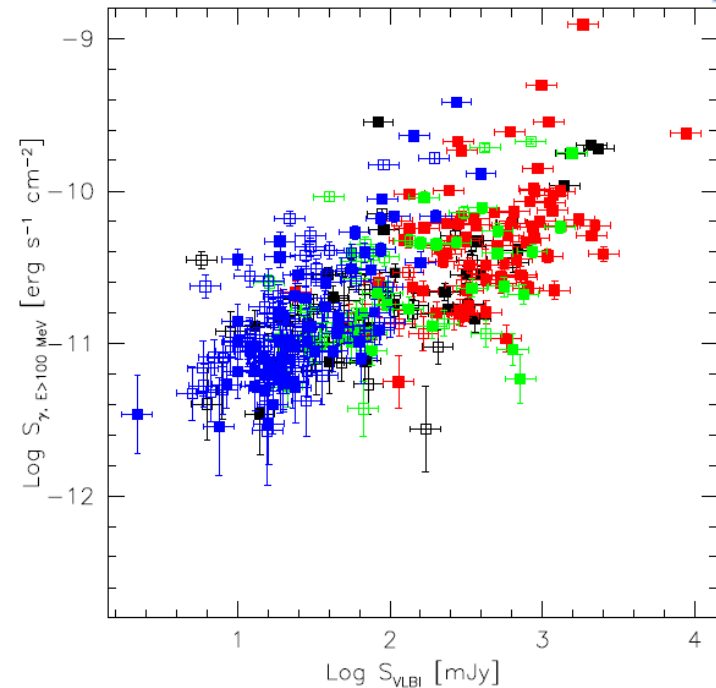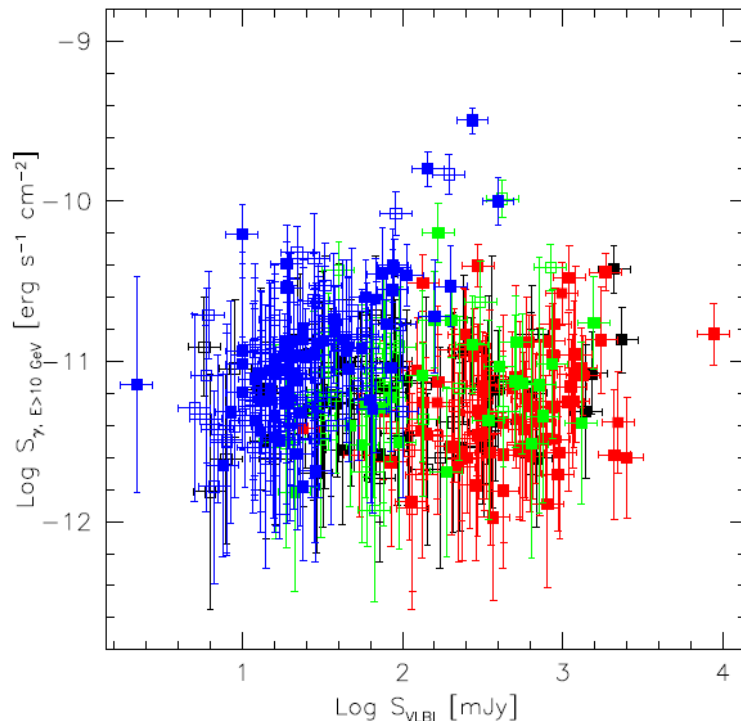- rising spectrum both in the 3FGL and 1FHL/2FHL catalogs.

Lico et al. 2017

Summary

Radio VLBI vs. soft γ-ray emission (3FGL):

- **Strong and significant correlation**
  r = 0.7, p < 10^{-6}.

Radio VLBI vs. hard γ-ray emission (1FHL & 2FHL):

- **No evidence for a correlation**
  full sample: r=-0.05.
- Strong correlation for **HSP objects**:
  r = 0.6, p = 10^{-6}.

Lico et al. 2017
A&A 606, A138

Thank you!