Radio and GeV-TeV γ-ray emission connection in the different blazar sub-classes

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AGN13

BEAUTY and the BEAST

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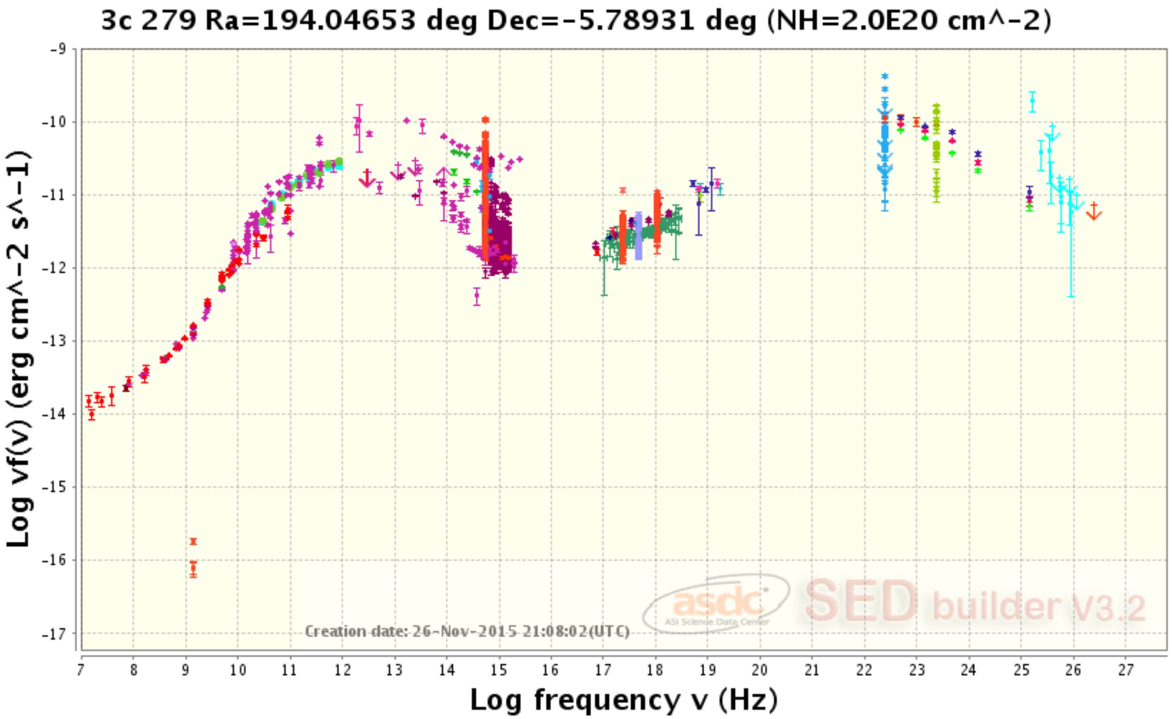
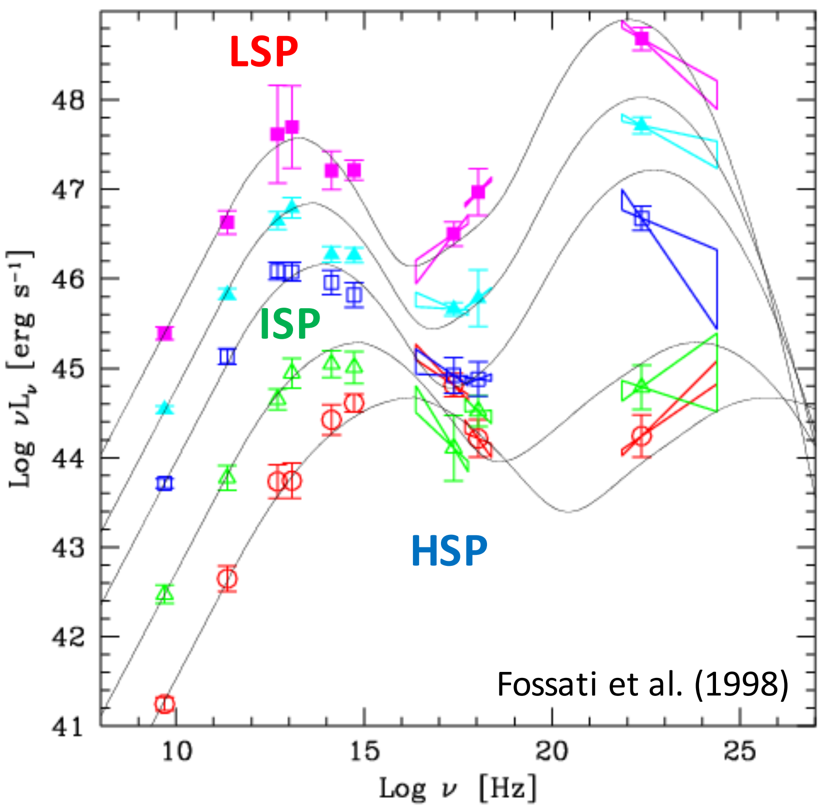
Spectral energy distribution (SED)



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



✓ Low synchrotron peaked **LSP**
$\nu_{s,peak} < 10^{14}$ Hz.

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

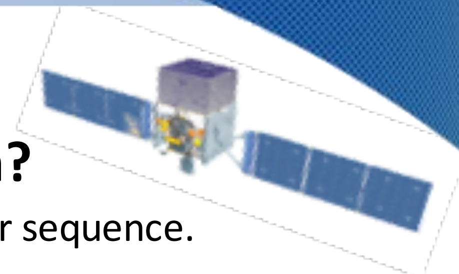
✓ High synchrotron peaked **HSP**
$\nu_{s,peak} > 10^{15}$ Hz.

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

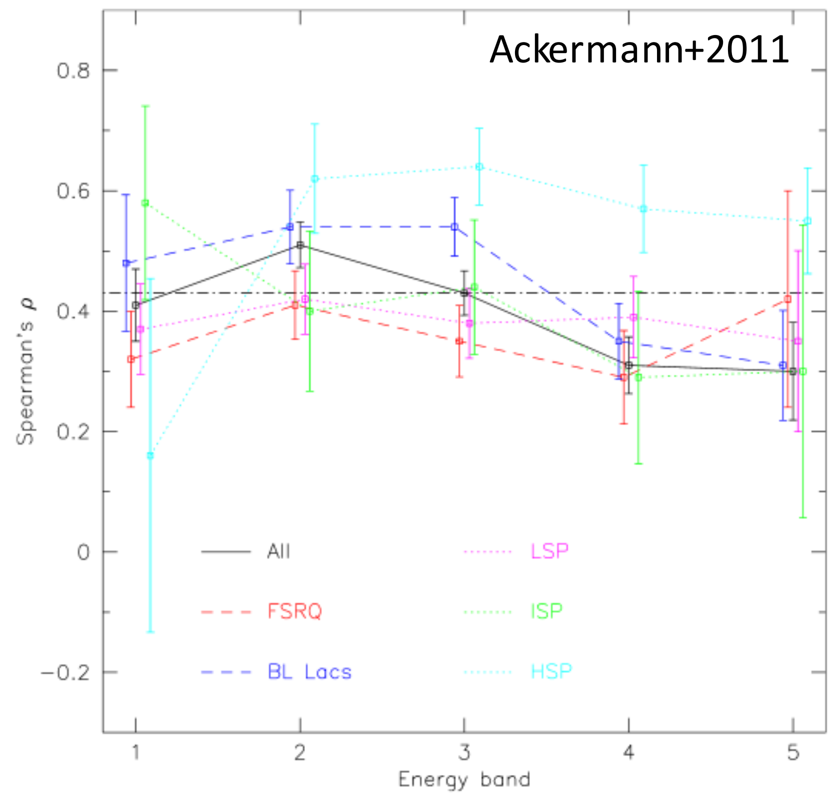


Is there any correlation between radio and γ-ray emission?

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

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.



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

Radio and VHE emission connection

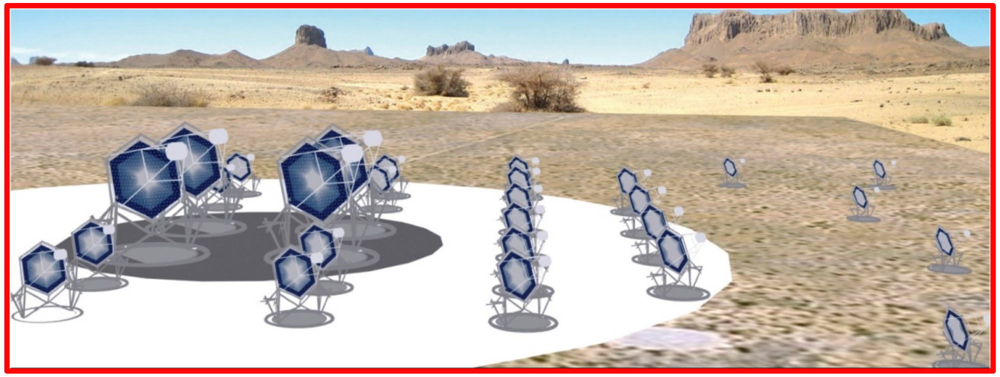
Is there any correlation between radio and VHE γ-rays?

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**



cta
cherenkov telescope array

1FHL *Fermi* catalog

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

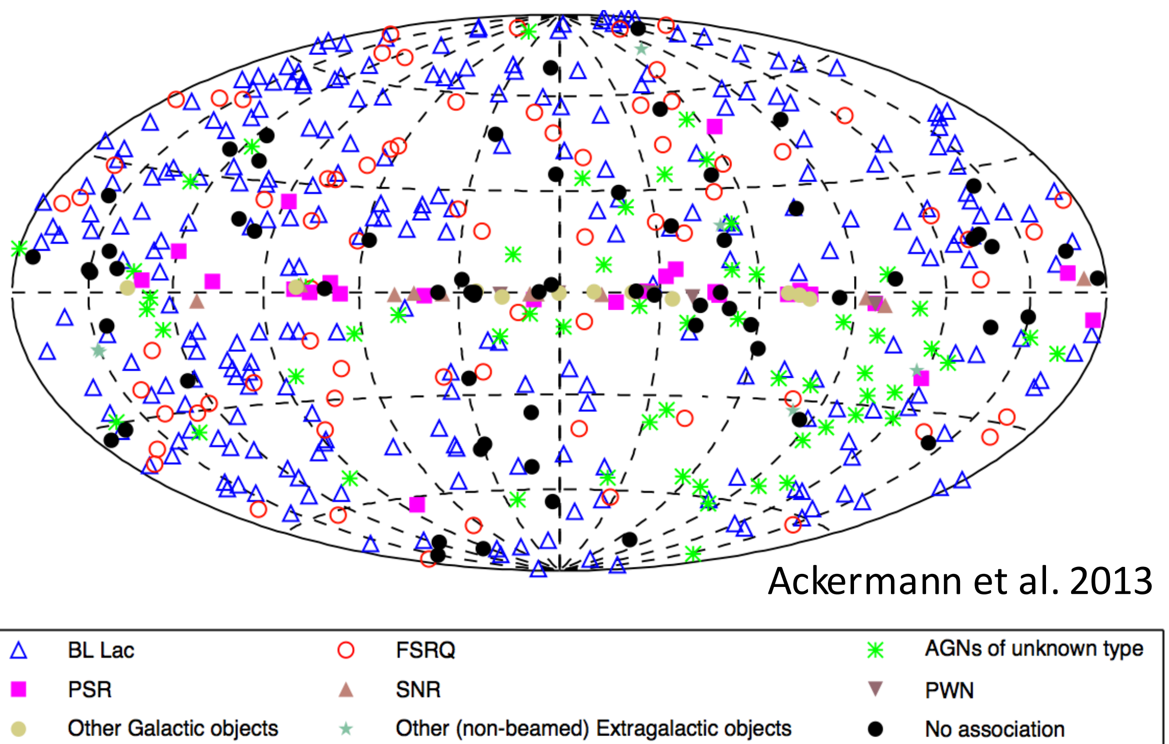
Why 1FHL?

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



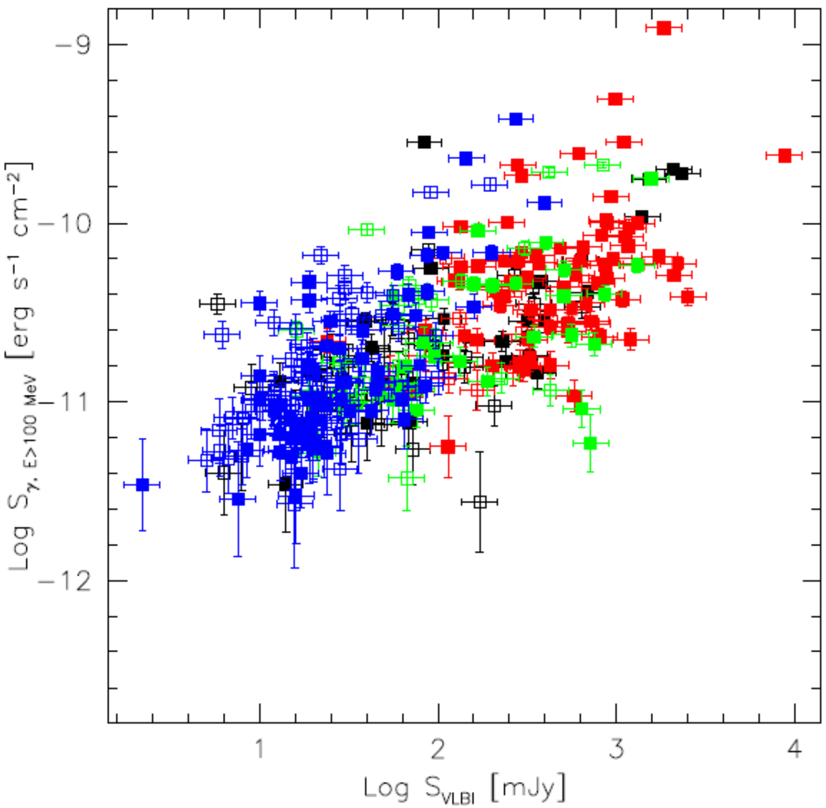
Ackermann et al. 2013

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

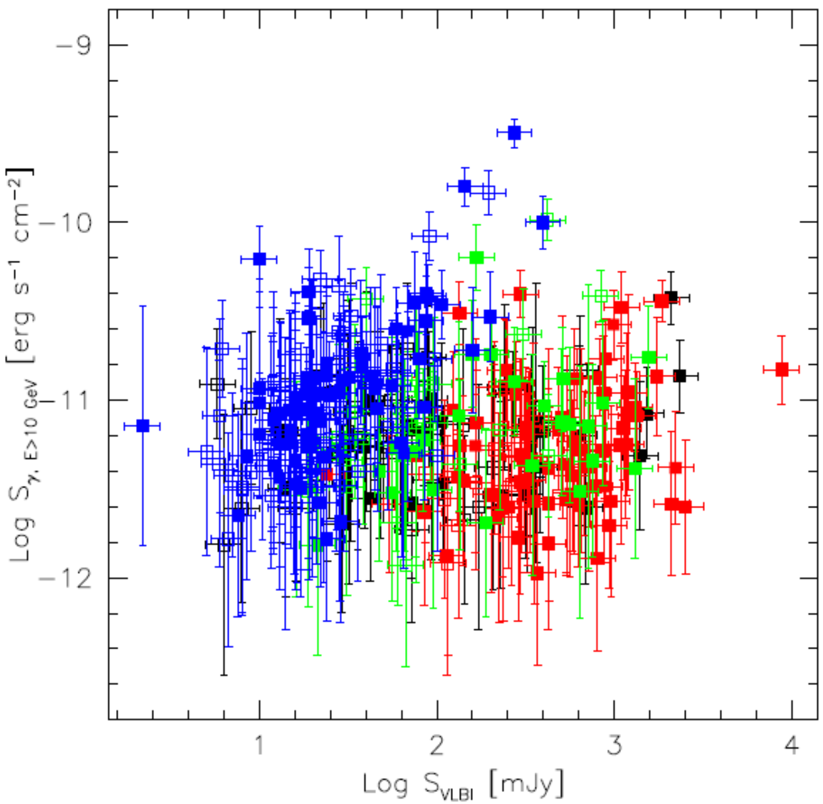
Correlation analysis: scatter plots

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	$\boxed{0.57}$	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. 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, FSRQs, BL Lacs, LSP, ISP).
- Strong and significant correlation for **HSP objects**.

2FHL *Fermi* catalog

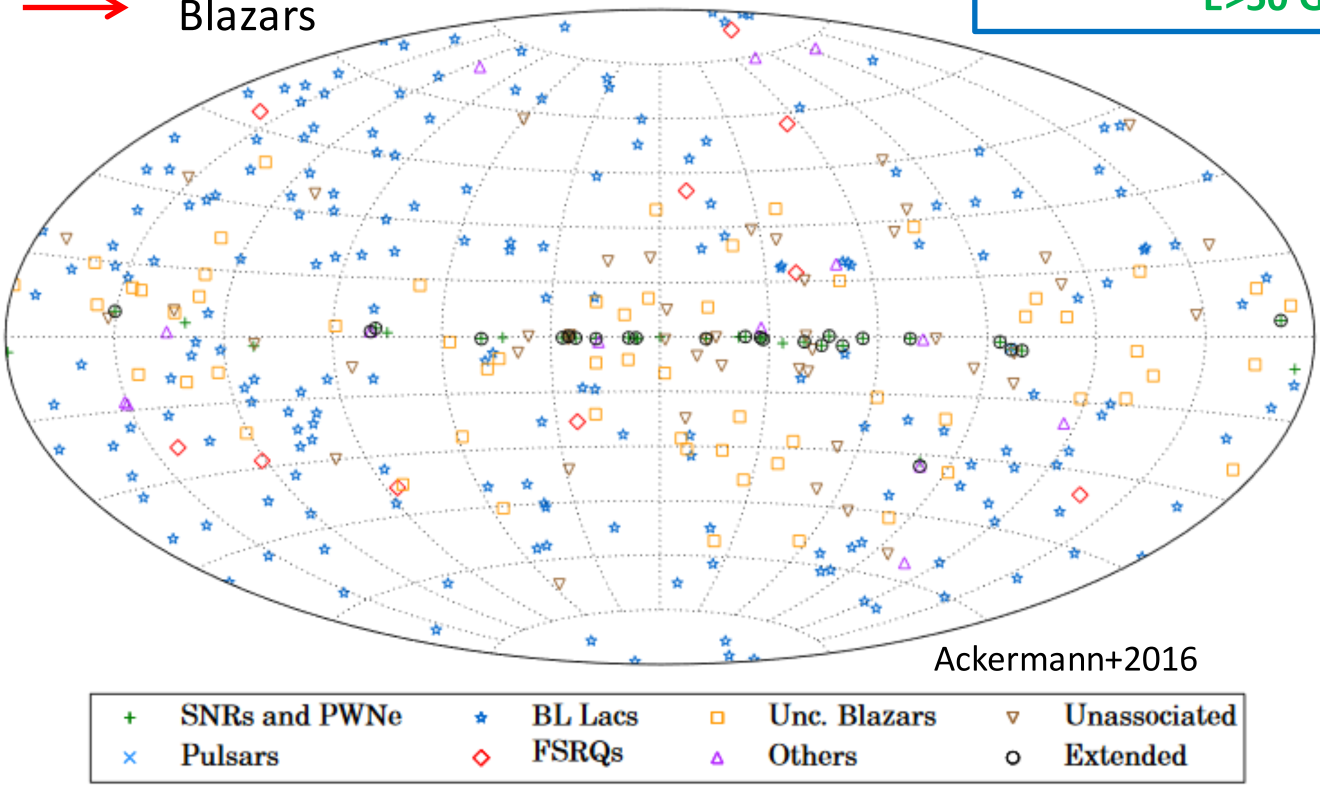
2FHL - Second *Fermi*-LAT catalog of HE sources above 50 GeV (Aug 2008 - Apr 2015).

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

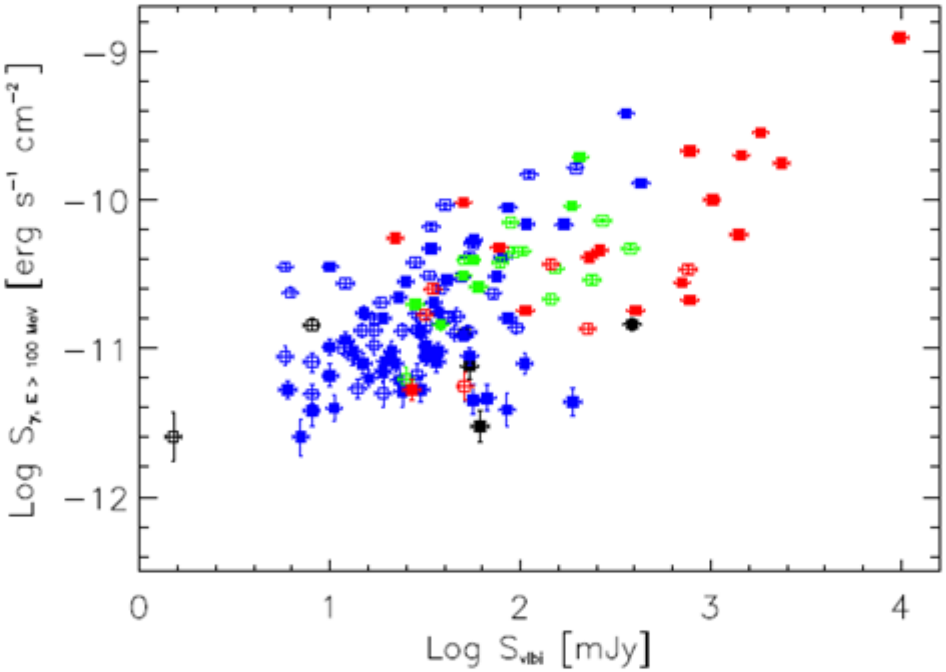


Ackermann+2016

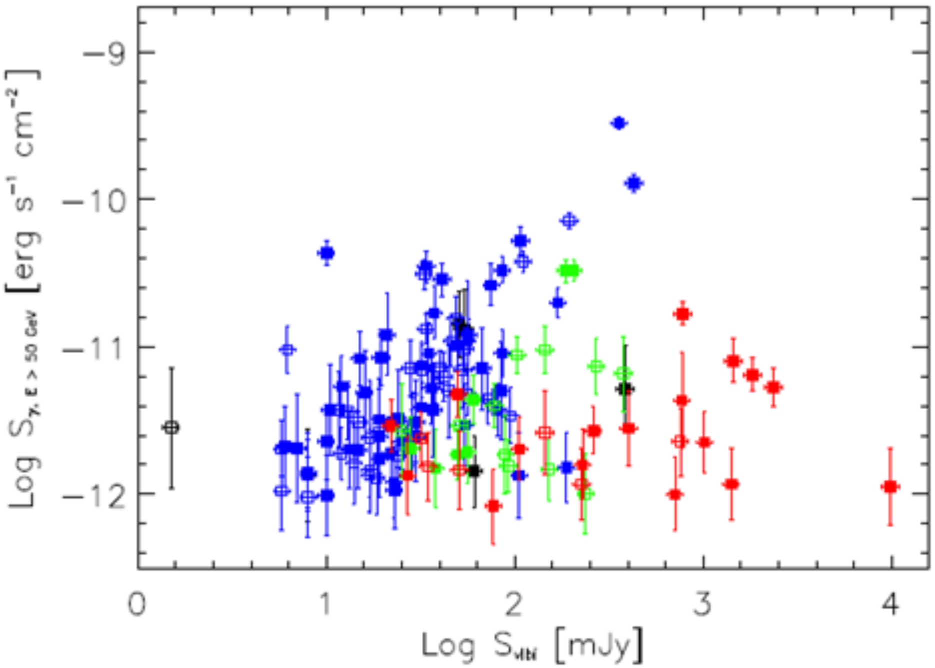
2FHL: scatter plots

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	$< 10^{-6}$
HSP - all	2FHL	84	8	0.61	$< 10^{-6}$
	3FGL	84	8	0.53	$< 10^{-6}$

Including HSP objects without know redshift

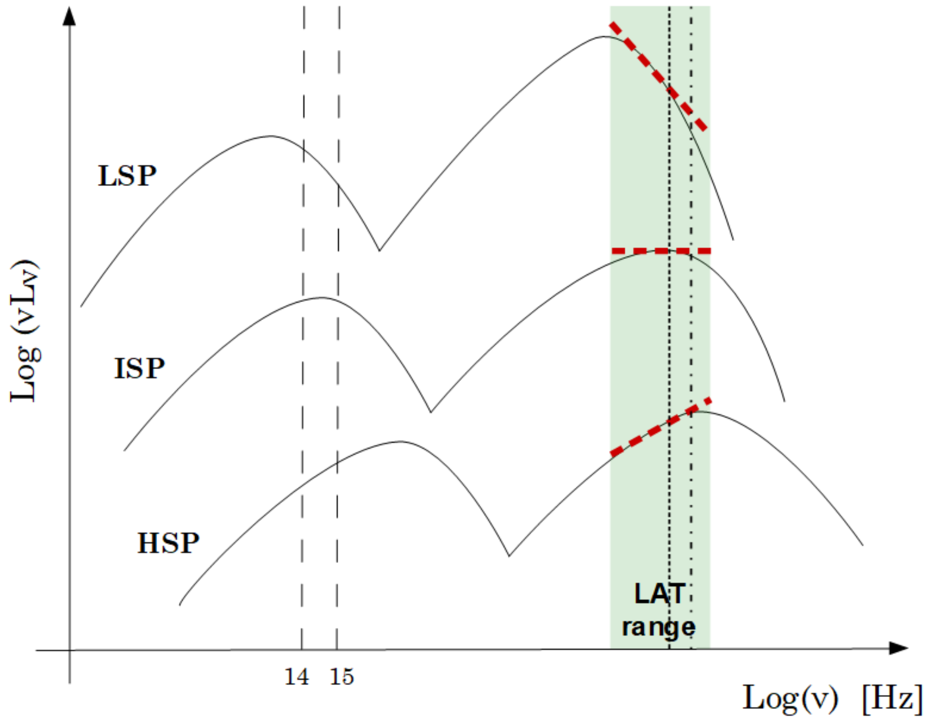
Radio VLBI vs. soft γ-ray emission (3FGL):

- 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):

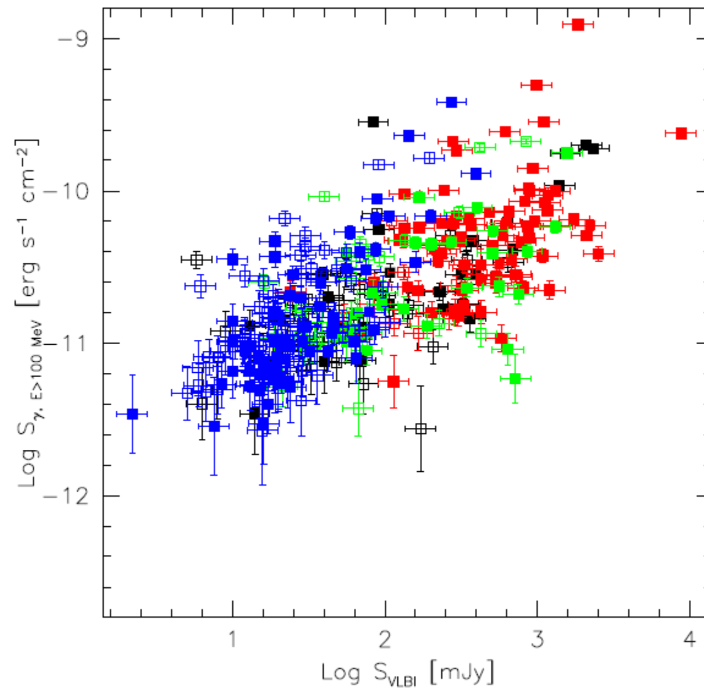
- soft γ-ray spectra -> HE component peaks at energies lower than those sampled by LAT;
- decreasing part of the spectrum, where the γ-ray flux is quickly decreasing;
- severe cooling losses of the emitting particles.

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.

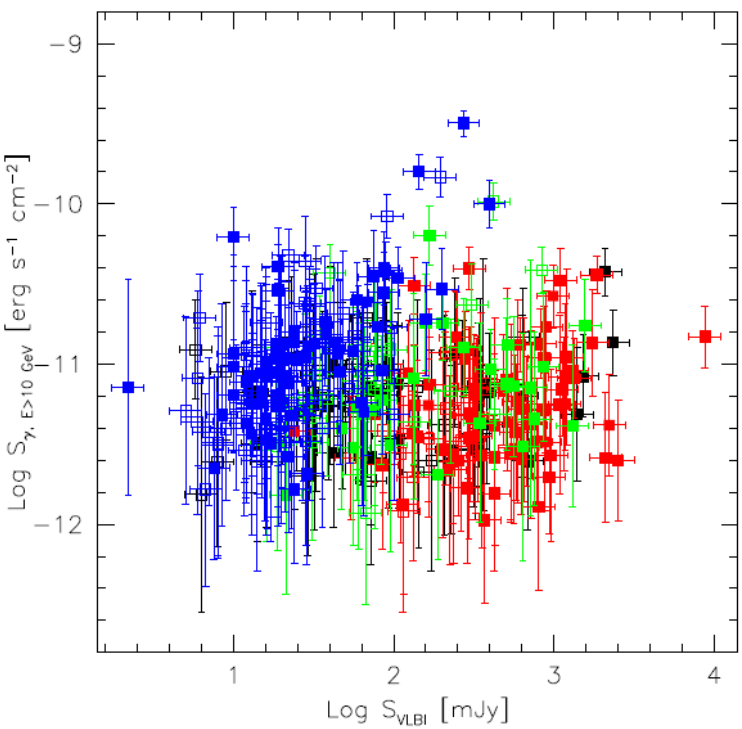
Lico+2017

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!