# On the radio and GeV-TeV γ-ray emission connection in *Fermi* blazars

**Presented by:**

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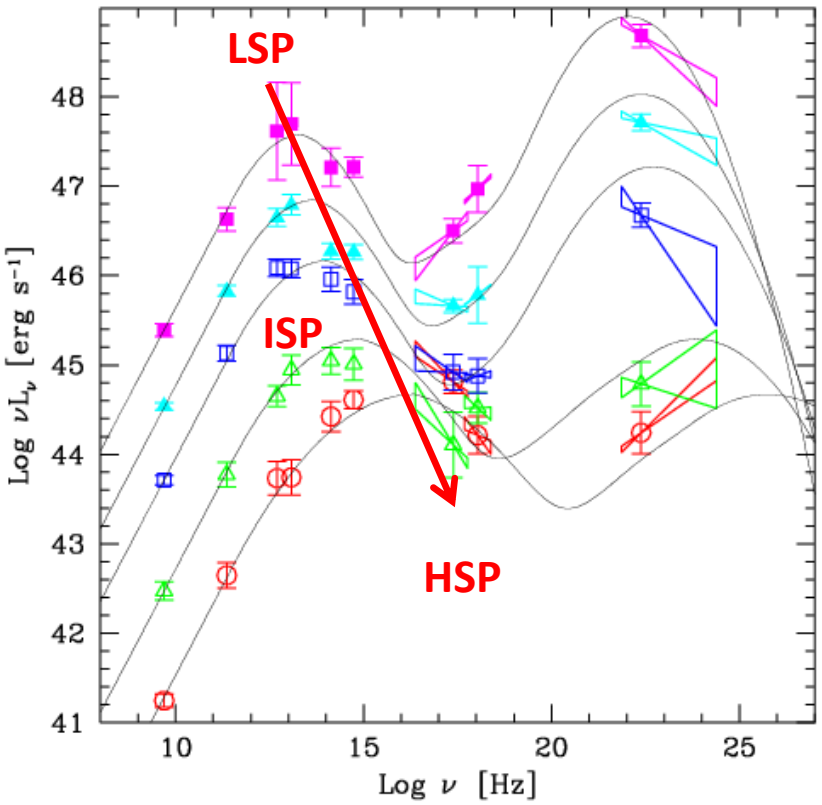
# Blazar spectral sub-classes

Fossati et al. (1998)



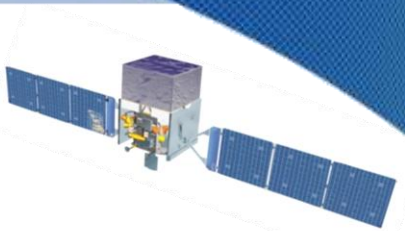

- ✓ Low synchrotron peaked **(LSP)**
  $\nu_{s,peak} < 10^{14}$ Hz.
- ✓ Intermediate synchrotron peaked **(ISP)**
  $10^{14}$ Hz $< \nu_{s,peak} < 10^{15}$ Hz.
- ✓ High synchrotron peaked **(HSP)**
  $\nu_{s,peak} > 10^{15}$ Hz.

**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

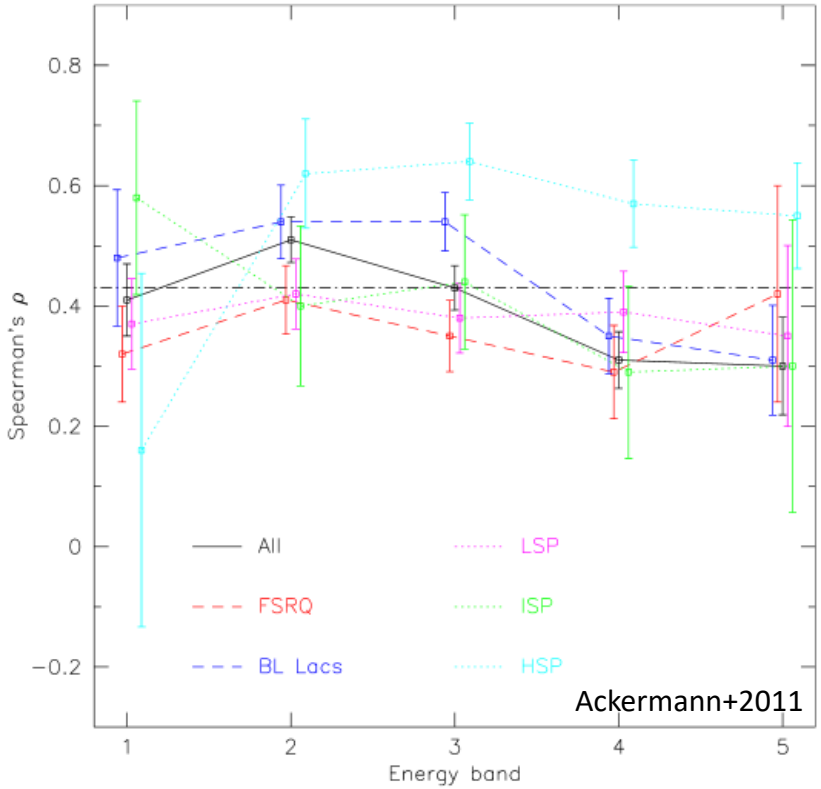
**The *Fermi*-LAT revealed that blazars dominate the census of the γ-ray sky**



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

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

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 strenght 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

CTA

Imaging atmospheric Cherenkov telescopes:

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

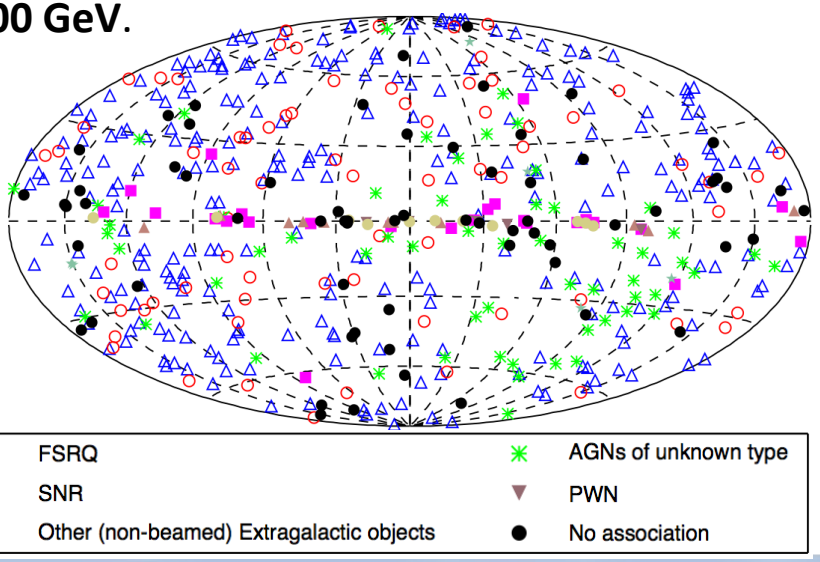
→ **VHE catalogs strongly biased**

1FHL - First *Fermi*-LAT catalog of sources above 10 GeV (Aug 2008 - Aug 2011).
Large, deep and unbiased sample in the energy range **10-500 GeV**.

**393/514** (76%) → AGNs

**330/393** (84%) → Blazars

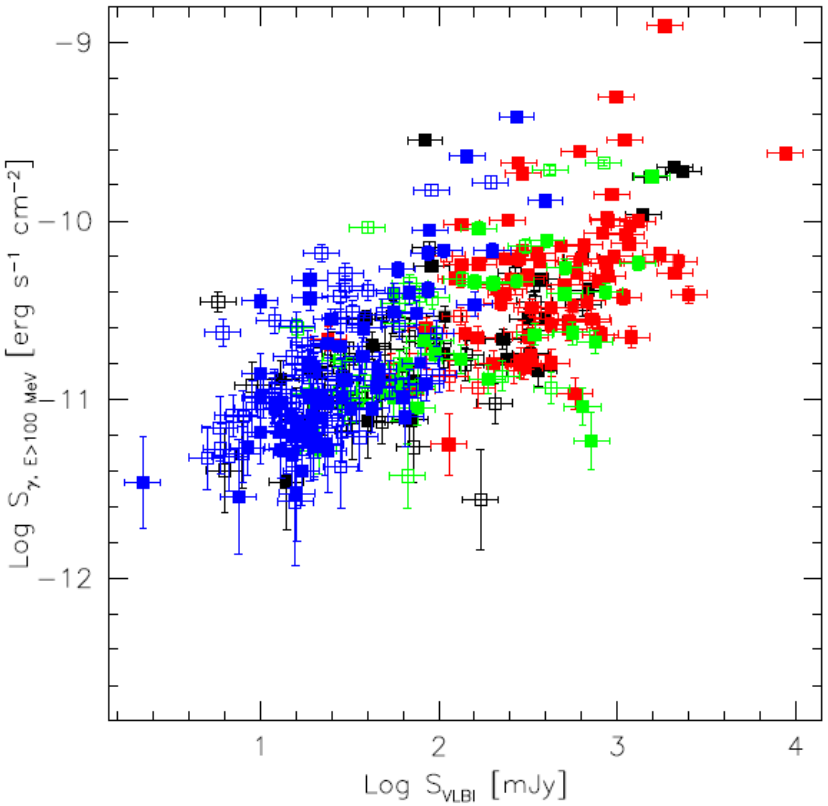
**Blazars dominate the γ-ray sky at E>10 GeV**



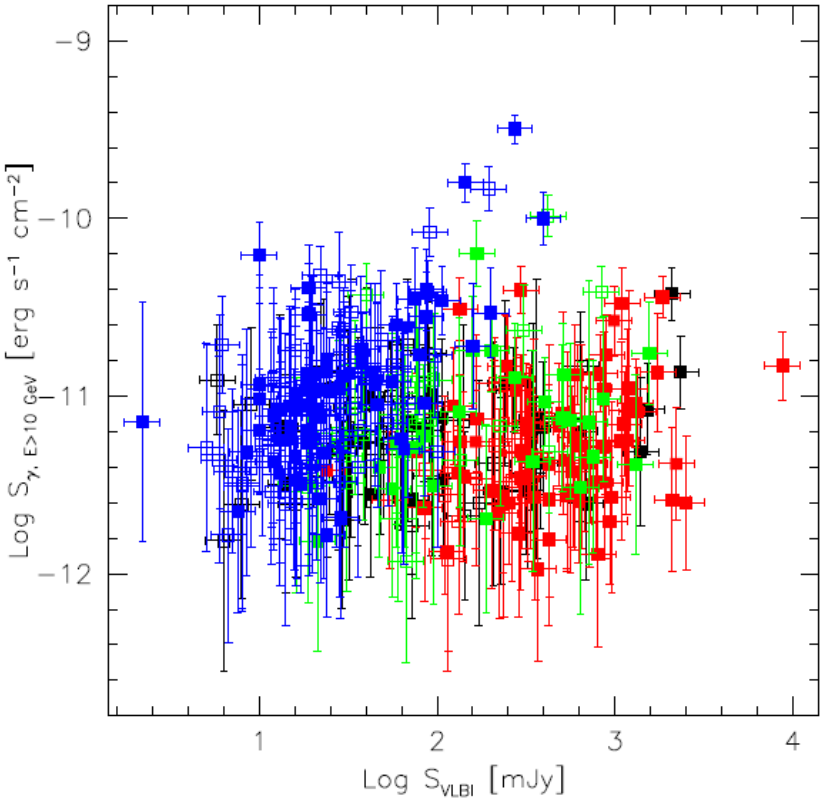
# Correlation analysis: scatter plots

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 | 0.57 | $1.0 \times 10^{-6}$ |
| | 3FGL | 60 | 5 | 0.77 | $< 10^{-6}$ |
| ISP | 1FHL | 23 | 2 | 0.19 | 0.40 |
| | 3FGL | 23 | 2 | 0.46 | $2.5 \times 10^{-2}$ |
| LSP | 1FHL | 52 | 5 | 0.21 | 0.12 |
| | 3FGL | 52 | 5 | 0.43 | $3.0 \times 10^{-6}$ |

**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.

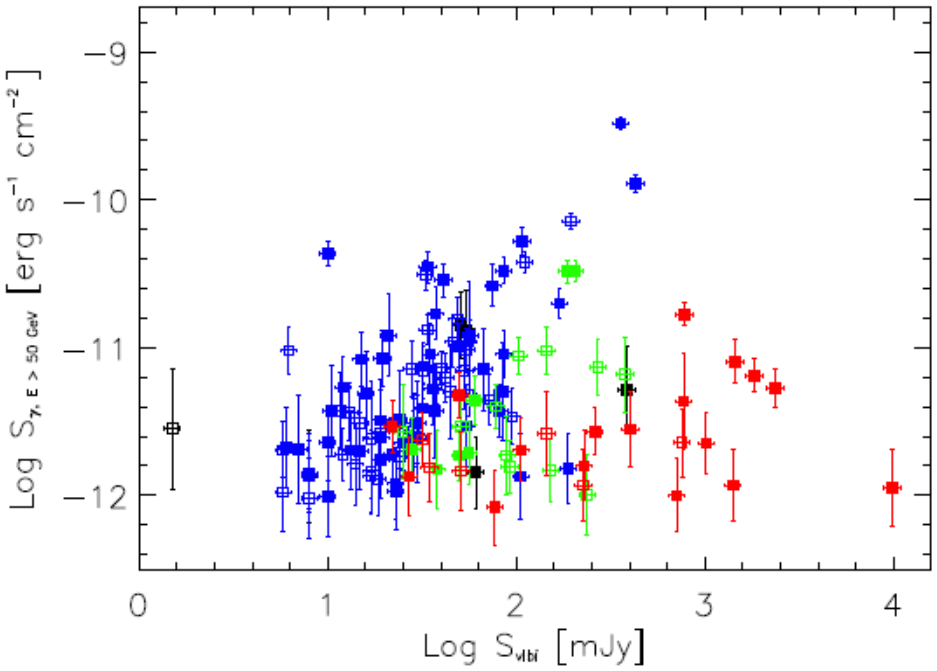
# 2FHL: scatter plots

**Second *Fermi*-LAT catalog of sources above 50 GeV (2FHL)**

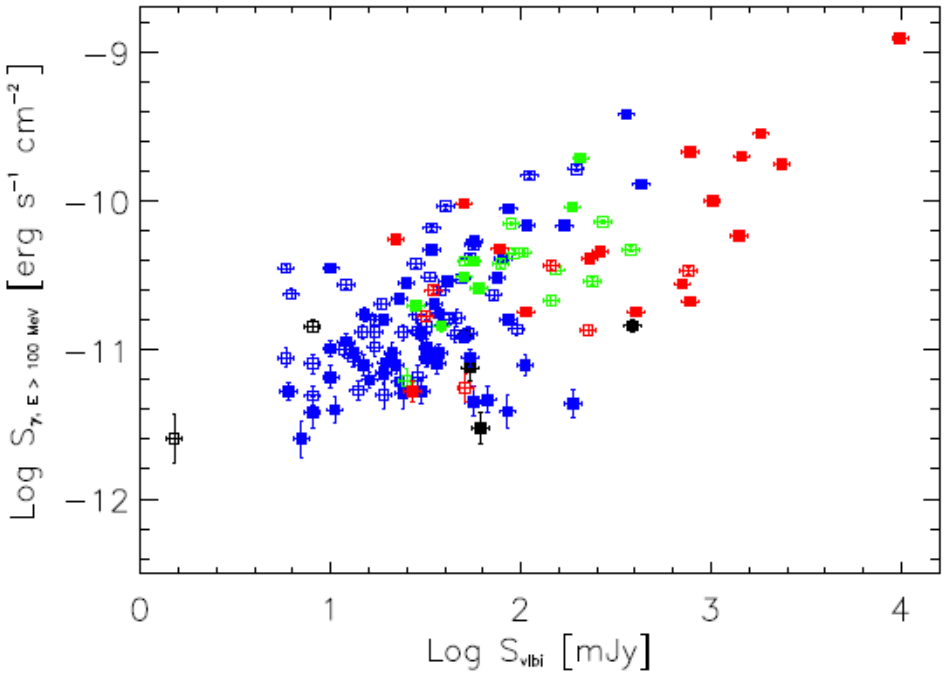
The **2FHL** contains 360 γ-ray sources detected by *Fermi*-LAT in the energy range between 50 GeV and 2 TeV, detected during the first 80 months of the mission.

131 sources

2FHL (50 GeV -2 TeV)




3FGL (0.1 - 300 GeV)




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 | $7.0 \times 10^{-6}$ |
| | 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**

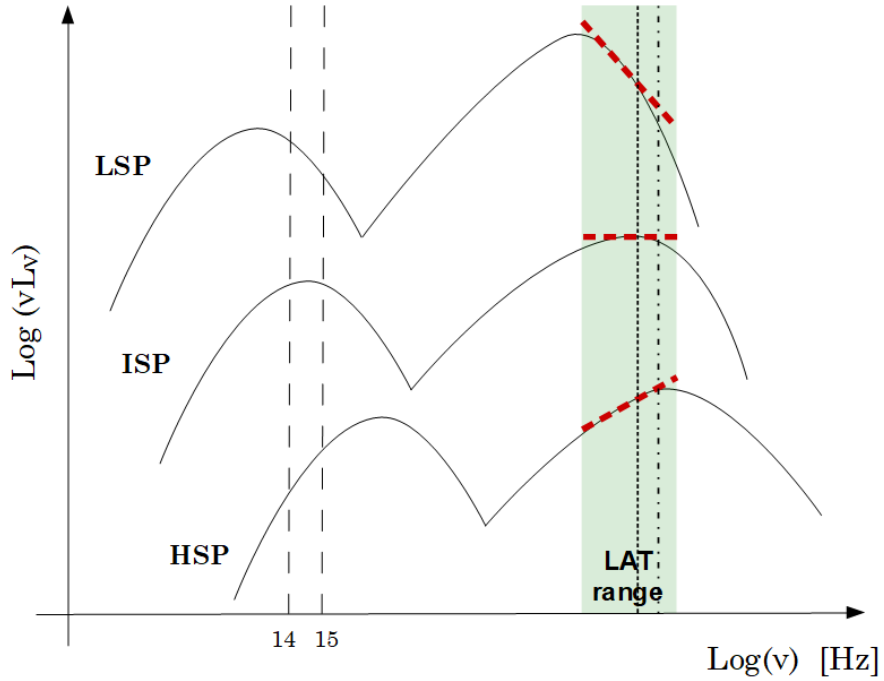
**Radio VLBI vs. hard γ-ray emission (1FHL):**

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

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

- Strong and significant correlation for all sub-classes.

# Correlation analysis: discussion




**Powerful objects** (i.e. FSRQs and BL Lacs of the LSP type):

- soft γ-ray spectra -> HE component peak at energies lower than those sampled by LAT;
- severe cooling losses of the emitting particles.

**Weak objects** (i.e. HSP objects):

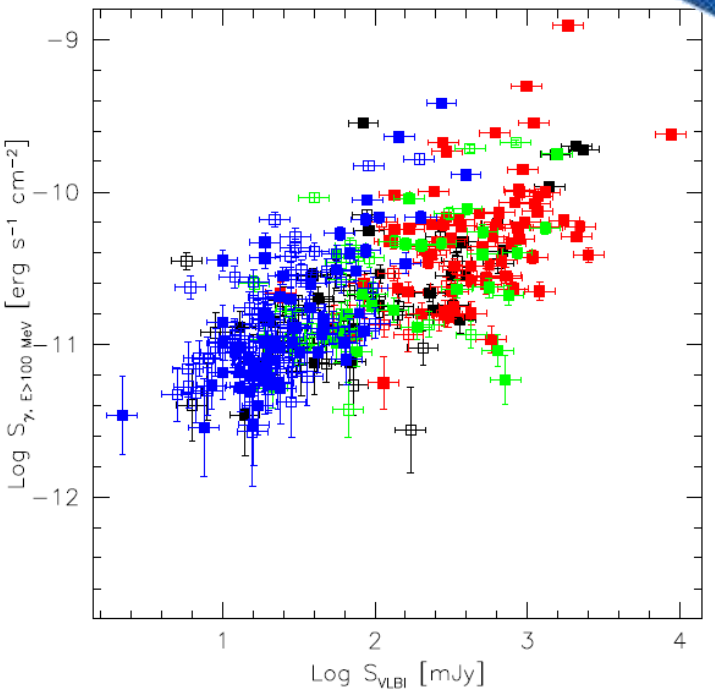
- Energy losses less severe -> HE peak which is above ~100 GeV.
- The part of the HE spectrum affected by cooling effects is beyond the LAT energy range;
- rising spectrum both in the 3FGL and 1FHL/2FHL catalogs.

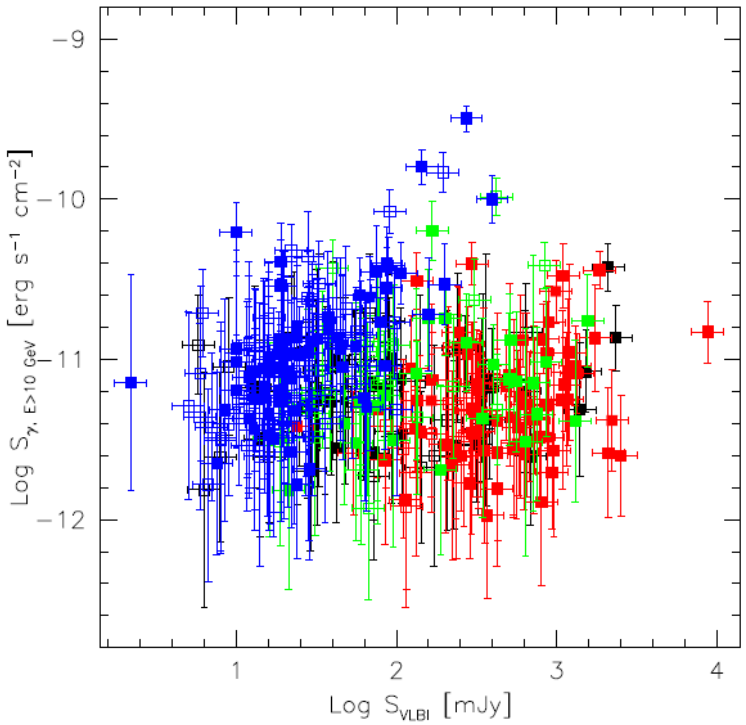
Lico et al. 2017

# 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
arXiv:1708.06201.

Thank you!