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)**
  \( v_{s,\text{peak}} < 10^{14} \text{ Hz} \).

- **Intermediate synchrotron peaked (ISP)**
  \( 10^{14} \text{ Hz} < v_{s,\text{peak}} < 10^{15} \text{ Hz} \).

- **High synchrotron peaked (HSP)**
  \( v_{s,\text{peak}} > 10^{15} \text{ Hz} \).

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 \( L_{\text{bol}} \).
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** \((p=9 \times 10^{-8})\) 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.

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

3FGL (0.1-300 GeV) 237 1FHL sources 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

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

**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.

Rocco Lico, IRA/INAF & UniBO

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

<table>
<thead>
<tr>
<th>Source type</th>
<th>Catalog</th>
<th>Number of sources</th>
<th>Number of z-bins</th>
<th>r-Pearson</th>
<th>Significance</th>
</tr>
</thead>
<tbody>
<tr>
<td>All sources</td>
<td>2FHL</td>
<td>76</td>
<td>7</td>
<td>0.13</td>
<td>0.36</td>
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<tr>
<td></td>
<td>3FGL</td>
<td>76</td>
<td>7</td>
<td>0.72</td>
<td>&lt; 10⁻⁶</td>
</tr>
<tr>
<td>BL Lac</td>
<td>2FHL</td>
<td>63</td>
<td>6</td>
<td>0.23</td>
<td>0.34</td>
</tr>
<tr>
<td></td>
<td>3FGL</td>
<td>63</td>
<td>6</td>
<td>0.73</td>
<td>&lt; 10⁻⁶</td>
</tr>
<tr>
<td>HSP - with z</td>
<td>2FHL</td>
<td>48</td>
<td>4</td>
<td>0.57</td>
<td>7.0 × 10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>3FGL</td>
<td>48</td>
<td>4</td>
<td>0.58</td>
<td>&lt; 10⁻⁶</td>
</tr>
<tr>
<td>HSP - all</td>
<td>2FHL</td>
<td>84</td>
<td>8</td>
<td>0.61</td>
<td>&lt; 10⁻⁶</td>
</tr>
<tr>
<td></td>
<td>3FGL</td>
<td>84</td>
<td>8</td>
<td>0.53</td>
<td>&lt; 10⁻⁶</td>
</tr>
</tbody>
</table>

Including HSP objects without known 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 y-ray emission (3FGL):
- Strong and significant correlation
  \[ r = 0.7, \ p < 10^{-6} \].

Radio VLBI vs. hard y-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

Thank you!