Radio Properties of Gamma-ray Emitting CSOs

Tao An¹, Yu-Zhu Cui¹, Willem A. Baan¹, Krisztina É. Gabányi², Sándor Frey², Wei Zhao¹

¹: Shanghai Astronomical Observatory, China
²: FOMI Satellite Geodetic Observatory, Hungary
γ-ray emitting AGN

What has Fermi found: The LAT two-year catalog

- 886 LAT bright AGN:
  - 310 FSRQs
  - 395 BL Lacs
  - 24 Other type AGN
  - 157 unknown

Aligned AGN

The population of misaligned AGN is increasing

Credit: NASA/Goddard Space Flight Center

Where does the γ-ray come from?
Where does the $\gamma$-ray come from?

- Many Gamma-ray flares in blazars from Superluminal knots moving down the jets
- Some may from BLR
Where does the $\gamma$-ray come from?

NASA's Fermi telescope resolves radio galaxy Centaurus A

Cheung et al. 2010
Science
Where does the γ-ray come from?

Cheung et al. 2010
Science
Where does the \( \gamma \)-ray come from?

Cheung et al. 2010 Science
γ-ray emission from CSOs

Kino et al. 2007

Sideways expansion of compact lobes/cocoons ⇒ MeV bremsstrahlung

The younger the cocoons, the brighter the γ-ray emitter.
γ-ray emission in GeV from cocoons of CSOs are predicted.
Inverse Compton scattering of synchrotron photons or external photon fields within lobes $\Rightarrow$ non-thermal X-ray and $\gamma$-ray emission

Siemiginowska et al. 2007

Stawarz et al. 2008
γ-ray CSOs: 4C +55.17

z=0.896  
EGRET: yes  
Fermi: yes  
First confirmed γ-ray CSO

Different from γ-ray blazars:
• Hard γ-ray spectrum  
• SED can be fitted with SSC+IC  
• No relativistic beaming  
• No variability in radio and γ-rays  
• $T_B \sim 10^8$ K  
• Extended radio morphology  
• Low radio polarization

Muller et al. 2014 A&A, 562, 4
**γ-ray CSOs: PMN J1603-4904**

Different from γ-ray blazars:
- A diffuse, extended emission component
- SED can be fitted with SSC+IC
- No variability in radio and γ-rays
- Spectral index: $\alpha = -0.4$
- $T_B \sim 10^{9-10}$ K
- CSO radio morphology
  ⇒ either a peculiar BL Lac or a CSO


**α = -0.4**

**No variability**
CSO - a new \( \gamma \)-ray AGN population?
Sample selection

From Fermi AGN catalog select:
- GPS or steep spectrum
- CSO morphology at pc-scale
<table>
<thead>
<tr>
<th>Name</th>
<th>Fermi name</th>
<th>z</th>
<th>$S_{\text{radio}}$ (Jy)</th>
<th>Morphology (kpc)</th>
<th>Morphology (pc)</th>
<th>Ref.</th>
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</thead>
<tbody>
<tr>
<td>0305+039</td>
<td>J0308.3+0403</td>
<td>0.029</td>
<td>0.25 - 0.36</td>
<td>core + diffuse</td>
<td></td>
<td></td>
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<tr>
<td>0646+600</td>
<td>J0650.9+6524</td>
<td>0.455</td>
<td>0.21 - 0.34</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>1508-055</td>
<td>J1510.9-0542</td>
<td>1.191</td>
<td>0.43 - 0.73</td>
<td>Compact core</td>
<td></td>
<td></td>
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<tr>
<td>2234+282</td>
<td>J2236.2+2828</td>
<td>0.79</td>
<td>0.44 - 1.49</td>
<td>one-sided lobe</td>
<td></td>
<td></td>
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<tr>
<td>1229-021</td>
<td>EGRET detection</td>
<td>1.045</td>
<td>0.339 - 0.397</td>
<td></td>
<td>two-sided core-jet</td>
<td>Zhao et al. in prep.</td>
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<tr>
<td>0202+149</td>
<td>J0204.5+1516</td>
<td>0.405</td>
<td>0.307 - 1.905</td>
<td></td>
<td></td>
<td>An et al. in prep.</td>
</tr>
<tr>
<td>PMNJ1603-404</td>
<td>J1603.9-4903</td>
<td>?</td>
<td>0.57 - 0.59</td>
<td></td>
<td></td>
<td>McConville et al. 2011</td>
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<tr>
<td>0954+556</td>
<td>J0957.6+5523</td>
<td>0.79</td>
<td>0.098</td>
<td></td>
<td></td>
<td>Muller et al. 2014</td>
</tr>
</tbody>
</table>
VLBI images of γ-ray CSO candidates

3FGL J0650.9+6524: compact double lobes

GPS

1FGL J1511.1-0545: compact double jets/lobes

Steep spectrum
VLBI images of γ-ray CSO candidates

**IFGL J0308.3+0403:**
- one-sided core-jet
- Steep spectrum

**IFGL J2236.2+2828:**
- compact double
- Flat or inverted
VLBI images of γ-ray CSO candidates

[HB89] 1229-021:
- EGRET: yes
- Fermi/LAT: no
- Steep spectrum
- Core + two-sided jets lobes
- Mild relativistic beaming

1FGL J0204.5+1516:
- EGRET: yes
- Fermi/LAT: yes
- Flat spectrum
- MSO at kpc-scale
- Core-jet at pc-scale
- $T_B^{core} \sim 10^{10.11}$ K
- $v_{app} \sim 2c$
γ-ray CSOs behave differently from γ-ray blazars in radio bands

- Compact radio structure (<1 kpc)
- Radio morphology: CSO, core-jet, or diffuse extended
- Low brightness temperature, low apparent speed $\Rightarrow$ no Doppler boosting
- Mild or moderate Lorentz factor
- No significant variability in radio or in γ-ray
- Low polarization
Open questions

• CSO a compact lobe - a new but important γ-ray origin?

• A large fraction of unidentified Fermi sources could be misaligned AGN, some could be CSOs

• γ-ray CSOs provide laboratory to study jet-ISM interactions

Future work:

Radio properties (jet proper motion, core brightness temperature, VLBI core dominance, degree of polarization) together with other information (SED, photon index) should be studied based on a mini-sample to constrain γ-ray radiation mechanisms in young radio AGN
Thank you!