The connection between millimeter and gamma-ray emission in AGNs

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The Large Area Telescope (LAT) onboard Fermi

- Since 2008, Fermi-LAT is continuously monitoring the gamma-ray sky in the energy range ~100 MeV-100 GeV.

- After 2 years, Fermi has detected 1017 gamma-ray sources located at high galactic latitude that are associated statistically with AGNs (2LAC, Ackermann et al. 2011 ApJ 743)
2LAC

- A clean sub-sample of the 2LAC includes 395 BLL, 310 FSRQ, 157 unknown, 8 misaligned AGNs, 4 NLS1 (very different from EGRET!)

- The sources are characterized in 5 energy bands - BLL are harder than FSRQ

- Radio data are available for all sources - BLL are fainter and less powerful than FSRQ - for both classes, low frequency (1-8 GHz) spectral index is typically flat

\[ \alpha = 0.08 \pm 0.27 \]
Short gamma-ray variability time scales

2155-304, HESS
Abramowski et al. 2010
TeV, doubling timescale ~2min

3C454.3, Fermi-LAT
Tavecchio et al. 2010
doubling timescale ~6hr
From gamma-rays to mm-wavelength

- Gamma-ray variability implies compactness, compactness implies low frequency self-absorption

- Fermi sources call for millimeter observations. Indeed, some interesting results were obtained by Planck, but due to sensitivity limitations we are far from a clear understanding of radio spectra and broad-band SED

\[ \nu_{\text{max}} = e(\alpha) \ H^{1/5} \ \theta^{-4/5} \ S_{\text{max}}^{2/5} \ (1 + z)^{1/5} \]
ALMA sensitivity for Fermi sources

- 1 min ALMA rms about 0.2, 0.3, 0.6, 5.3 mJy beam$^{-1}$ at 100, 230, 345, and 675 GHz

- let's assume $\alpha = 0.5$ ($S \propto \nu^{-\alpha}$), this correspond to high significance detections for tens of Fermi blazars - note that the most intriguing sources have even flatter observed spectra

- still, no structural information

- need VLBI for that...
VLBI with ALMA?

- At present, Global Millimeter VLBI Array (GMVA)
  - ~14 participating telescopes (6 Europe, 8 VLBA) - Noto, SRT in the future(?)
  - 2 sessions per year
  - Baseline sensitivity 50-350 mJy
  - Angular resolution 40 μas

<table>
<thead>
<tr>
<th>mm-VLBI</th>
<th>current</th>
<th>with ALMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>sensitivity</td>
<td>100 mJy</td>
<td>10 mJy</td>
</tr>
<tr>
<td>resolution</td>
<td>50 μas</td>
<td>10 μas</td>
</tr>
</tbody>
</table>
Angular and spatial resolution of mm-VLBI

<table>
<thead>
<tr>
<th>λ</th>
<th>ν</th>
<th>θ</th>
<th>z=1</th>
<th>z=0.01</th>
<th>d= 8 kpc</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 mm</td>
<td>86 GHz</td>
<td>45 μas</td>
<td>0.36 pc</td>
<td>9.1 mpc</td>
<td>1.75 μpc</td>
</tr>
<tr>
<td>2 mm</td>
<td>150 GHz</td>
<td>26 μas</td>
<td>0.21 pc</td>
<td>5.3 mpc</td>
<td>1.01 μpc</td>
</tr>
<tr>
<td>1.3 mm</td>
<td>230 GHz</td>
<td>17 μas</td>
<td>0.13 pc</td>
<td>3.4 mpc</td>
<td>0.66 μpc</td>
</tr>
</tbody>
</table>

- for nearby sources, these scales correspond to 1–100 Schwarzschild radii, depending on distance and black hole mass!

- linear size: $10^3R_s$ (log $M_{BH}$=9), 30-100 $R_s$ (log $M_{BH}$=9), 1-5 $R_s$ (log $M_{BH}$=6)

- mm-VLBI is able to directly image the vicinity of SMBHs!

- best candidates: Sgr A*, M87
A near candidate for BH horizon: the radio galaxy M87

- d=16 Mpc
- low power but bright FR1 radio galaxy
- most massive black hole in nearby universe: \( M_{\text{BH}} = 10^9 \, M_{\text{sun}} \)
- Schwarzschild radius \( R_S = 3.7 \, \mu\text{as} \)
- optical and X-ray jet with superluminal motions
- source detected at GeV/TeV energy
Coordinated VHE and MWL variability

- 2008: bright, fast TeV flare detected from all TeV telescopes (Acciari et al. 2009)
- VLBA 43 GHz radio core flux density increase
- (...but other TeV event show different MWL/radio characteristic, e.g. Harris et al. 2006, Giroletti et al. 2012)
M87 with present mm-VLBI

size of the jet base: 197×54 µas = 21×6 light days = 69×19 Rs
transverse width of jet at 0.5 mas: ~174 Rs
clear transverse structure, counter-jet feature?
Locating the black hole in M87

Hada et al. 2012, Nature

to BH, via ALMA/VLBI
CREATING A BLACK HOLE TELESCOPE

230 GHz VLBI of Sgr A*
Doeleman et al. (2008)
10 & 11 April 2007 @3.84 Gbit/s
Fitting and resolving the size of Sgr A* with 1.3 mm VLBI

Doeleman et al. (2008)

Ring ("doughnut")
outer diameter: 80 μas, inner diameter: 35 μas

HHT-Carma
Gaussian size: 43 μas

Carma-JCMT
HHT-JCMT
Summary and outlook

• ALMA sensitivity and operating wavelength are ideal to access regions were gamma rays are most likely produced in AGNs

• As an element of a mm-VLBI array, ALMA will allow us to directly image the SMBH vicinity