Fermi and Non-Blazar AGN

C.C. Teddy Cheung (NRC/Naval Research Lab) on behalf of the Fermi-LAT Collaboration
Non-Blazar ("Other") $\gamma$-ray AGN

<table>
<thead>
<tr>
<th>AGN Type</th>
<th>Entire 1LAC Sample</th>
<th>High-confidence Sample$^a$</th>
<th>Clean Sample$^a$</th>
</tr>
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<tbody>
<tr>
<td>All</td>
<td>709</td>
<td>663</td>
<td>599</td>
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<tr>
<td>FSRQ</td>
<td>296</td>
<td>281</td>
<td>248</td>
</tr>
<tr>
<td>...LSP</td>
<td>189</td>
<td>185</td>
<td>171</td>
</tr>
<tr>
<td>...ISP</td>
<td>3</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>...HSP</td>
<td>2</td>
<td>2</td>
<td>1</td>
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<tr>
<td>BL Lac</td>
<td>300</td>
<td>291</td>
<td>275</td>
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<tr>
<td>...LSP</td>
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<td>67</td>
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<tr>
<td>...ISP</td>
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<td>44</td>
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</tr>
<tr>
<td>...HSP</td>
<td>118</td>
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<tr>
<td>Other AGN</td>
<td>41</td>
<td>30</td>
<td>26</td>
</tr>
<tr>
<td>Unknown</td>
<td>72</td>
<td>61</td>
<td>50</td>
</tr>
</tbody>
</table>

1LAC sample contains 709 AGN associated with 671 1FGL gamma-ray sources ($|b|>10$ deg)

High-confidence Sample: P>80% assoc. probability

Clean Sample: P>80% and single AGN/1FGL

LAT team leads: Healey, Cavazzuti, Gasparrini, Lott, Tosti

*see E. Cavazzuti et al.'s poster on 2LAC

2011 May 10  Fermi Symposium - Cheung
Our Nearest Non-blazar AGN

Fermi data reveal giant gamma-ray bubbles

M. Su’s talk yesterday

2011 May 10

Fermi Symposium - Cheung
Our Nearest Non-blazar AGN

Gamma-ray emissions

X-ray emissions

Milky Way

50,000 light-years

Sun

2011 May 10

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Flaring in Sgr A*

NASA/CXC/Caltech/M. Muno et al.

Rapid X-ray/IR/mm/sub-mm variability
Marrone et al. 2008

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Radio Jet Activity in Nearby AGN

- Circinus galaxy (D~4 Mpc)
- Radio lobes highly polarized with extent ~6 kpc
- Hosts low-luminosity AGN

ATCA λ13cm image
Elmouttie et al. (1998)
AGN-related Gamma-rays from Seyferts?

BAT hard X-ray Seyfert sample

Jet model for NGC1068

All γ-ray points are upper limits

\[ \frac{L_\gamma}{L_X} = 1 \]

\[ 0.1 \]

\[ 0.01 \]

But NGC1068 (and other LAT detected nearby AGN) have prominent starburst emission

* see M. Hayashida et al. poster
**γ-ray Variability Search in nearby AGN**

- **Sgr A***
  - Fig. 1: Fermi / LAT, 0.1–200 GeV
  - XMM / EPIC, 2–10 keV
  - Flare S

- **Trap et al. 2011**

- **Swift J1644+57 ("GRB110328A")**
  - BAT 14–195 keV
  - XRT 0.3–10 keV

- **2011 May 10**

- **Fermi Symposium - Cheung**

- **Tidal disruption event in z=0.35 galaxy?**

- **Burrows et al. 2011**
  - see also Bloom et al., Levan et al.
\textbf{γ-ray Activity in Non-blazar AGN}

Evolving young radio source

Cen A radio galaxy
ATCA/Parkes λ20cm image

Feain et al. (2010)

Radio-quiet AGN

2011 May 10

Fermi Symposium - Cheung
Radio galaxies as an emerging γ-ray source population from Fermi-LAT
- γ-ray site and emission mechanism from LAT imaging
- Constraints from γ-ray and multi-wavelength variability

Young radio sources as candidate γ-ray sources
- see radio galaxy presentations by N. Galante, P. Grandi, J. Kataoka (talk), S. Lombardi, J. Perkins, [others?]
- see young radio source presentations by W. McConville, M. Orienti
- RG contribution to MeV background – AGN (Bhattacharya poster, Inoue poster), lobes (Massaro & Ajello poster)
- UHECRs from nearby LAT AGN (Nemmen poster)

Radio-loud narrow line Sy1s (Cavazzuti & Ghisellini talk; Foshini talk)
- Nearby AGN with dominant starbursts emitting γ-rays (2010 ApJL 709, L152)
- No clear cluster γ-ray emission detected so far (2010 ApJ 717, L71); Hydra A (poster by M. Ali)
Non-blazar Gamma-ray Population

Glean jet structure from SED modeling including LAT spectra:
- Are inferred $\theta$ larger than blazars?
- Are inferred jet velocities lower than in blazars?
- Jet structures?

LAT Mis-aligned AGN paper
LAT lead: P. Grandi
*see P. Grandi et al.’s poster
Blazars \quad \textup{Radio Galaxies, Lobe-dominated Sources}

from Urry & Padovani (1995)
Gamma-ray blazar jets typically characterized by: $\gamma > 10$, $\theta < 10^\circ$ (rapid variability, superluminal motions); high-E emission from pc-scale or smaller.

At larger $\theta$, "blazar jets" fade; more likely to see slower jet emission.

Spine-sheaths?

Unification

But possible emission from outside of "core" (e.g. extended jet, lobes, cluster)

From Urry & Padovani (1995)
Gamma-ray Radio Galaxies

LAT provides precise γ-ray localizations, \( \text{radii} \) (95%) \( 1.5 - 5 \) arcmin (vs. 0.5° in EGRET) correspond to \( 5 - 25 \) kpc for sources within 100 Mpc.

<table>
<thead>
<tr>
<th>Name</th>
<th>D/Mpc</th>
<th>MeV/GeV Detection</th>
<th>VHE?</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cen A</td>
<td>3.7</td>
<td>EGRET, LAT 2010</td>
<td>yes</td>
<td>Lobes</td>
</tr>
<tr>
<td>M87</td>
<td>16</td>
<td>LAT 2009</td>
<td>yes</td>
<td>TeV Var</td>
</tr>
<tr>
<td>Fornax A</td>
<td>18</td>
<td>LAT 2011</td>
<td></td>
<td>Preliminary</td>
</tr>
<tr>
<td>Cen B</td>
<td>56</td>
<td>LAT 2011</td>
<td></td>
<td>Preliminary</td>
</tr>
<tr>
<td>Per A</td>
<td>75</td>
<td>LAT 2009 (COS-B?)</td>
<td>yes**</td>
<td>Variable GeV + TeV</td>
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<tr>
<td>IC310</td>
<td>80</td>
<td>LAT 2010 (Neronov+)</td>
<td>yes</td>
<td>Head-tail, TeV</td>
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<tr>
<td>NGC6251</td>
<td>106</td>
<td>EGRET, LAT 2010</td>
<td></td>
<td></td>
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<tr>
<td>3C78</td>
<td>124</td>
<td>LAT 2010</td>
<td></td>
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<tr>
<td>3C120</td>
<td>142</td>
<td>LAT 2010</td>
<td></td>
<td>BLRG*</td>
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<tr>
<td>3C111</td>
<td>213</td>
<td>EGRET, LAT 2010</td>
<td></td>
<td>BLRG*</td>
</tr>
</tbody>
</table>

*J. Kataoka’s BLRG talk tomorrow, ** S. Lombardi’s poster
NASA’s Fermi telescope resolves radio galaxy Centaurus A

- Nearest radio-loud AGN
- Radio source extent ~10°
- At D=3.7 Mpc, L=600 kpc

LAT resolution = 0.8° at 1 GeV can image lobes

γ-ray color (purple) with optical galaxy

NASA/DOE/Fermi LAT Collab., Capella Obs.
Over $\frac{1}{2}$ of the total >100 MeV observed LAT flux in the lobes

Background & point sources subtracted

LAT
>200 MeV

WMAP
20 GHz

From Nils Odegard (GSFC)

2010 Science, 328, 725; Leads: Cheung, Fukazawa, Knodlseder, Stawarz

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IC (CMB+EBL) origin of LAT emission with $B \sim 1 \, \mu G$ in both lobes, near equipartition
- IC component dominant, $U_{\text{CMB}}/U_B \sim 10$ -- ‘requires’ the lower $B$-field in Cen A lobes than typical in other (more powerful) examples
- Predictions for hard X-ray emission, but not yet detected by INTEGRAL (Beckmann et al. arXiv:1104.4253)

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- LAT γ-ray emission dominated by IC/CMB component for the modeled electron energy spectra (broken power-law + exponential)
- Could probe EBL as IC/EBL dominates here at higher-energies, >GeV
**Gamma-ray Probe of EBL at >GeV Energies?**

- LAT γ-ray emission dominated by IC/CMB component for the modeled electron energy spectra (broken power-law + exponential)
- Could probe EBL as IC/EBL dominates here at higher-energies, >GeV

*See J. Perkins et al. poster for improved statistics and expanded energy coverage in analysis 29-months of LAT data analysis*
Inverse-Compton γ-ray Lobes in Fornax A?

IC/X-ray lobe B-field ~1.5 µG (Feigelson et al. 1995, Isobe et al. 2006)

- High EBL
- Low EBL

Georganopoulos et al. (2008)

LAT 68% and 95% confidence ellipse on radio image

LAT team leads: McConville, Georganopoulos

2011 May 10

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\(\gamma\)-rays from NGC6251: inverse-Compton Lobes?

- Associated with 3EG J1621+8203 (Mukherjee et al. 2002) with large error circle

- Large radio galaxy (1.2° ~ 1 Mpc) so LAT capable of spatially separating lobe from AGN emission

- Lobe equipartition B-field \(~0.3\, \mu\text{G}\) (Mack et al. 1996); cf. \(~1\, \mu\text{G}\) for Cen A

LAT 68% and 95% confidence ellipse on radio image

also Migliori et al., submitted
MeV/GeV emission can be modeled as 1-zone synchrotron self-Compton from core with moderate jet beaming: $\delta \sim 2-4$

Does not preclude $\gamma$-rays from outside the radio core

LAT leads: Cheung, McConville
M87: 3 TeV Events

Credit: HESS, MAGIC, VERITAS, Fermi-LAT, many MWL partners

*see N. Galante’s poster

leung
M87: 3 TeV Events

- 2005 TeV flare (HESS) coincided with X-ray/UV/radio flaring in knot HST-1 (>120 pc); Cheung et al. 2007

Credit: HESS, MAGIC, VERITAS, Fermi-LAT, many MWL partners

*see N. Galante’s poster*
2005 TeV flare (HESS) coincided with X-ray/UV/radio flaring in knot HST-1 (>120 pc); Cheung et al. 2007

2008 TeV flare (VERITAS, MAGIC, HESS) coincided with radio flaring in core (sub-pc); Acciari et al. 2009

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M87: 3 TeV Events

- 2005 TeV flare (HESS) coincided with X-ray/UV/radio flaring in knot HST-1 (>120 pc); Cheung et al. 2007
- 2008 TeV flare (VERITAS, MAGIC, HESS) coincided with radio flaring in core (sub-pc); Acciari et al. 2009
- 2010 TeV ~20% Crab (historical high) now with Fermi-LAT, VLBA, and Chandra coverage

Credit: HESS, MAGIC, VERITAS, Fermi-LAT, many MWL partners

*see N. Galante’s poster*
Gamma-ray Variability in NGC 1275 = 3C84

Year timescale γ-ray & radio variability

LAT 3-month & 11-month localizations (95%)

Flaring in 2009 with >GeV hardening (Kataoka et al. 2010)

Brighter flare in 2010 (Donato et al. Atel 2737) with VHE detection

Discovery of Very High Energy Gamma-Ray Emission from NGC1275 by MAGIC

ATel #2916: Mose Mariotti (INFN and Univ. of Padova) on behalf of the MAGIC Collaboration
on 10 Oct 2010; 15:00 UT
Distributed as an Instant Email Notice Request For Observations
Credential Certification: Mose Mariotti (mariotti@pd.infn.it)

Subjects: Gamma Ray, >GeV, TeV, VHE, AGN, Blazar, Cosmic Rays

The MAGIC Collaboration reports the detection of Very High Energy (VHE) gamma-ray emission from a position consistent with NGC 1275, the central radio galaxy of the Perseus cluster of galaxies.

The MAGIC observations were carried out in stereoscopic mode starting from August 2010, accumulating 14 h of good quality data. Preliminary analysis using the standard analysis chain with an energy threshold of 100 GeV, shows an excess of 280 gamma-rays, corresponding to a statistical significance of 5.2 standard deviations. The observed flux is estimated to be ~3% of the Crab nebula flux above 100 GeV, and it decreases rapidly with energy. No signal is detected above 400 GeV.

The MAGIC VHE detection happened during a period of increased high gamma-ray activity of NGC 1275, as reported in July 2010 by the Fermi/LAT collaboration, ATel#2737, and continuing until October, according to an analysis of public Fermi/LAT data.

MAGIC will continue observations of NGC1275. Observations at other wavelengths are encouraged.

MAGIC consists of two 17m diameter imaging air Cherenkov telescopes located on La Palma, Canary Islands, Spain.

Questions regarding the MAGIC observations should be directed to Mose Mariotti (mose.mariotti@pd.infn.it)

MAGIC VHE detection
* See Lombardi et al. poster

Previous VERITAS and MAGIC limits
Acciari et al. 2009, Aleksic et al. 2010

Brown & Adams (2011)
Correlated Radio Flares?

2009 Apr-May  2010 Jul-Aug

LAT >0.8 GeV

MOJAVE: https://www.physics.purdue.edu/astro/mojave/
Coincidence with Radio Flares?

2009 Apr-May
LAT >0.8 GeV

2009 May
Peak 3.4 Jy
MOJAVE VLBA 15 GHz
MOJAVE: https://www.physics.purdue.edu/astro/mojave/

2010 Jul-Aug
Peak 3.7 Jy
Peak 4.8 Jy

1 mas = 0.35 pc

Young Radio Source?
Compact (<1 kpc – 10’s kpc) radio sources constitute large fraction in cm-wavelength surveys

These “GPS/CSS” sources are powerful, $L_{5\,\text{GHz}} > 10^{25}$ W/Hz (FR-II radio galaxies in miniature)

Intrinsically small and powerful (negligible projection and Doppler effects)

Model expectations for gamma-rays in lobes – leptonic (Stawarz et al. 2008) and hadronic (Kino et al. 2007, 2009)

Gugliucci et al. (2005), Begelman & Cioffi (1989)
4C+55.17: a Young Radio Source?

- Flat-spectrum radio quasar, z=0.9
- VLBI extent ~400 pc, projected

*see W. McConville poster*
4C+55.17: a Young Radio Source?

- Flat-spectrum radio quasar, $z=0.9$
- VLBI extent $\sim 400$ pc, projected

*see W. McConville poster

Rossetti et al. (2005)
4C+55.17: an Unusual LAT AGN

- Brightest steady LAT detected γ-ray AGN, after Cen A
- Hard MeV/GeV spectrum (especially for a quasar)
- LAT VHE detection of 145 GeV photon (275 GeV rest frame)
- Gamma-ray lobe emission?

McConville et al., submitted
Non-Blazar ("Other") AGN

- Radio galaxies as an emerging $\gamma$-ray source population from Fermi-LAT
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