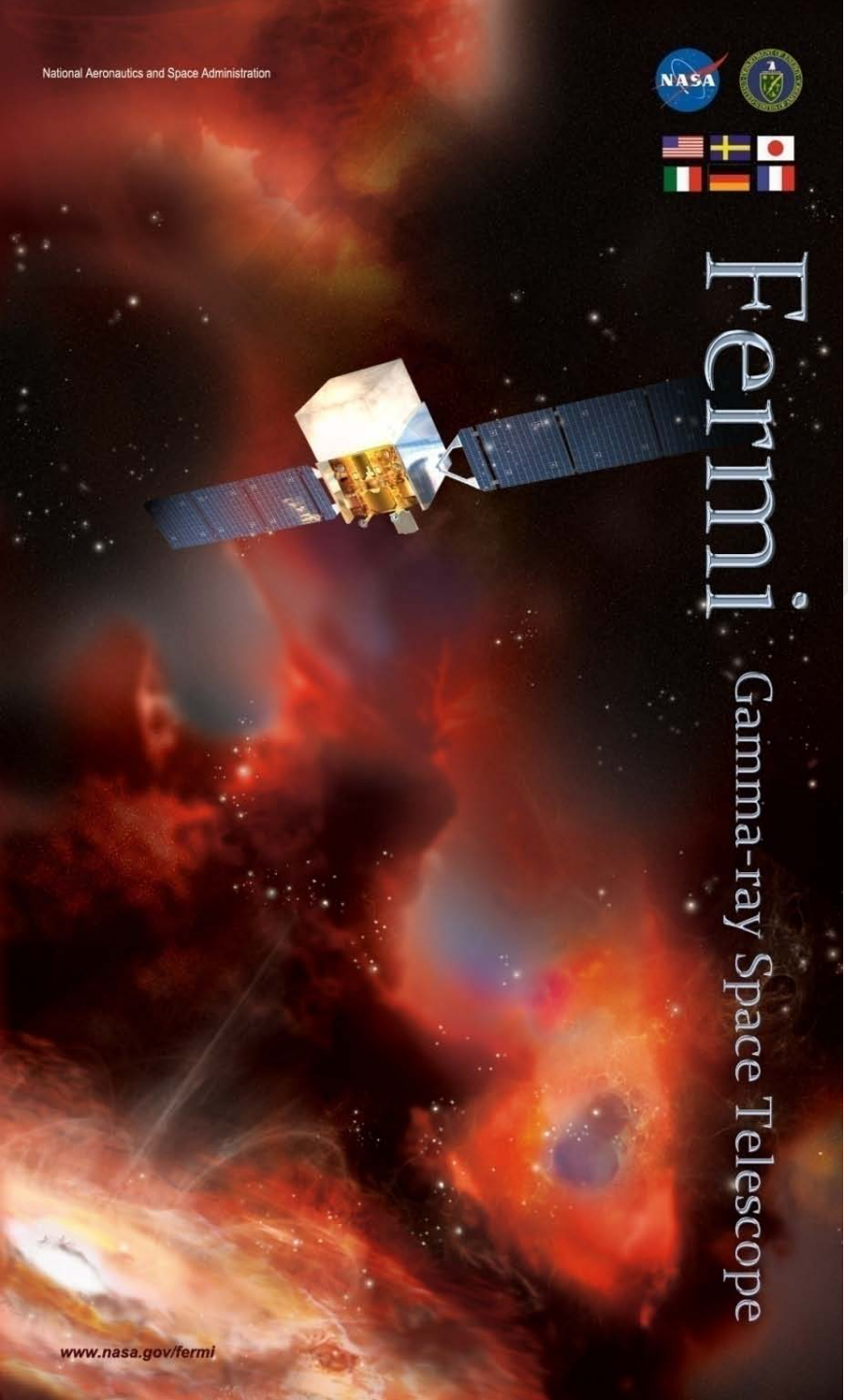



Fermi Gamma-ray Space Telescope

# Non-Blazar Gamma-ray Active Galactic Nuclei seen by Fermi-LAT

**C.C. Teddy Cheung**

**Naval Research Lab/NRC**

**on behalf of the Fermi-LAT Collaboration**

# 1st LAT AGN Catalog (1LAC) Summary

- Entire 1LAC: |b|>10 deg (671 1FGL/709 AGN)
- High-confidence Sample: P>80%
- **Clean Sample: P>80% and single AGN/1FGL**

**Table 4**
Census of 1LAC Sources

| AGN Type | Number of AGNs in | | |
|---|---|---|---|
| | Entire 1LAC Sample | High-confidence Sample[a] | Clean Sample[a] |
| All | 709 | 663 | 599 |
| FSRQ | 296 | 281 | 248 |
| ...LSP | 189 | 185 | 171 |
| ...ISP | 3 | 2 | 1 |
| ...HSP | 2 | 2 | 1 |
| BL Lac | 300 | 291 | 275 |
| ...LSP | 69 | 67 | 62 |
| ...ISP | 46 | 44 | 44 |
| ...HSP | 118 | 117 | 113 |
| Other AGN | 41 | 30 | 26 |
| Unknown | 72 | 61 | 50 |

This Talk

1LAC: 2010 ApJ, 715, 429; arXiv:1002.0150
Leads: Healey, Cavazzuti, Gasparrini, Lott, Tosti

# 1LAC: "Other AGN"

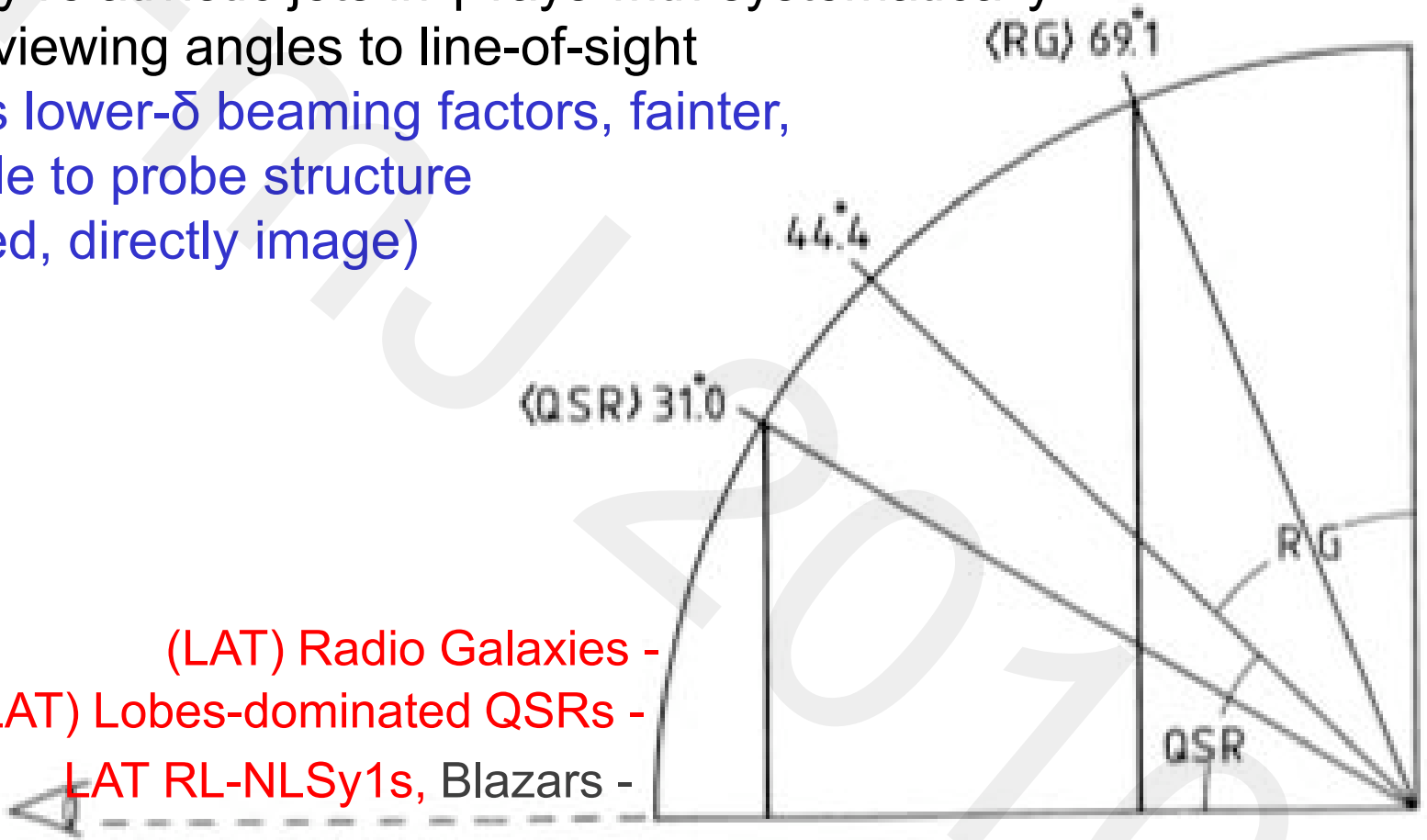
- Radio-loud narrow line Sy1s
- Lobe-dominated radio quasars
- ➔ Radio galaxies, including detection of Cen A lobes*

All sources have variable, bright radio cores – same underlying phenomena of compact relativistic jets as blazars (*except Cen A lobes)

- Narrow-line radio galaxies
- Young radio source? 4C+55.17 (McConville), also 3C84 (Nagai, Kellermann), and see Kino's & Orienti's posters
- Radio-quiet source: ESO 323-G77, nearby Sy1.2
- Starburst galaxies (2010 ApJL 709, L152) and e.g., NGC4945 (1LAC)
- No cluster detections so far (arXiv:1006.0748)

# What do we expect?

- Study relativistic jets in γ-rays with systematically larger viewing angles to line-of-sight
- Thus lower-δ beaming factors, fainter, possible to probe structure (inferred, directly image)

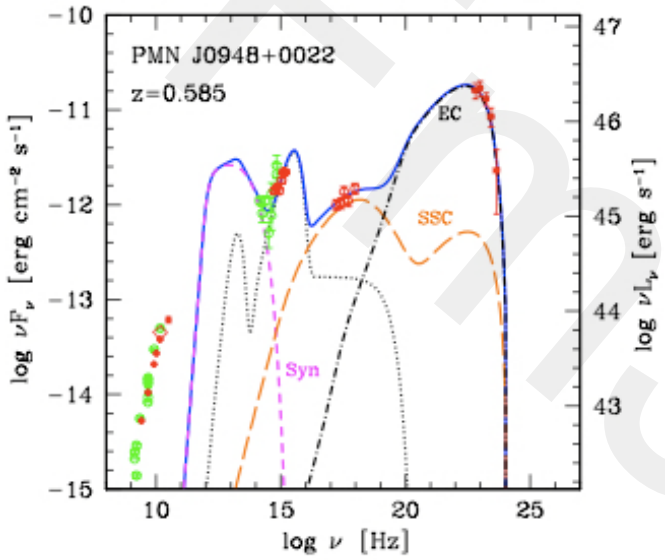


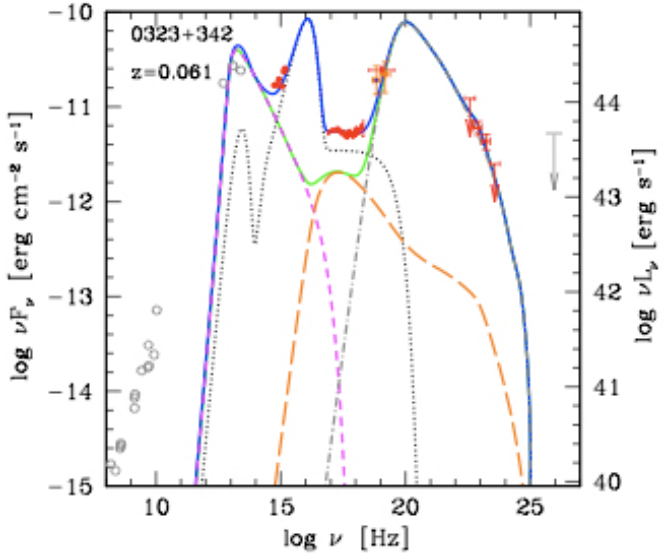

(LAT) Radio Galaxies -
(LAT) Lobes-dominated QSRs -
LAT RL-NLSy1s, Blazars -

FIG. 2.—The QSR–RG unification model: RGs oriented within 44°.4 from the line of sight will be observed as QSRs. The relative foreshortening follo
average QSR and RG orientations.

Barthel (1989)

# Radio-loud Narrow-Line Seyfert 1s (RL-NLSy1s)



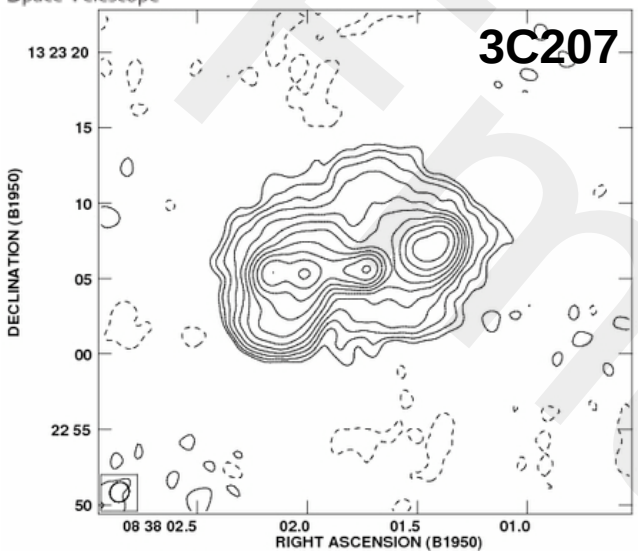

- NLSy1s show permitted lines: [OIII]/Hβ <3, FWHM(Hβ)<2000 km/s
- RL-NLSy1s typically spiral hosts
- Variable, high $T_B$ radio core

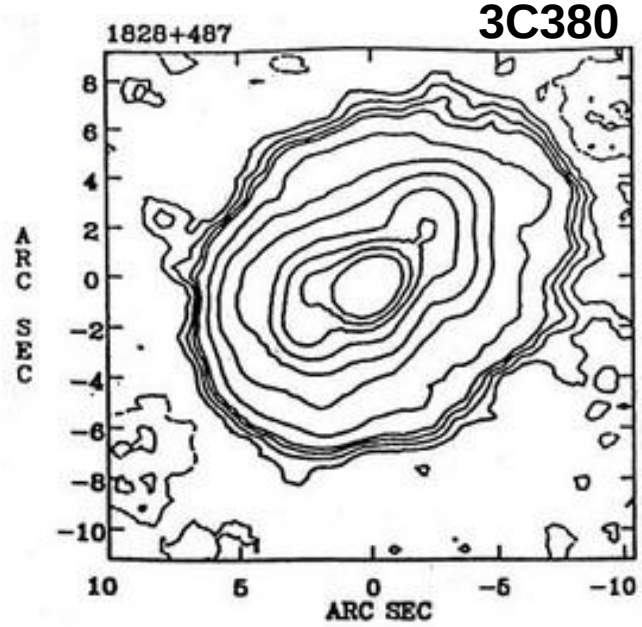
- Strong optical/UV disk emission
- Typically lower $M_{BH}$ estimated (~$10^7$ – $10^8$ $M_{sun}$)
- High-accretion rates (>80% Eddington)

- Highly relativistic jet in radio and gamma-rays !

2009 ApJL, 707, L142; Lead: L. Foschini

# Lobe-Dominated Quasars (LDQs)




- Radio spectra dominated by extended lobe emission
- Bridge the gap between blazars and radio galaxies

- LAT detected LDQs have variable, high $T_B$ radio cores
- Exhibit superluminal motions

(3C207 and 3C380 13-14c from MOJAVE)

- Also detected broad-line radio galaxy 3C 407 (z=0.59)

- Highly relativistic jet in gamma-rays !

Kharb et al. (2010); Murphy et al. (1993)

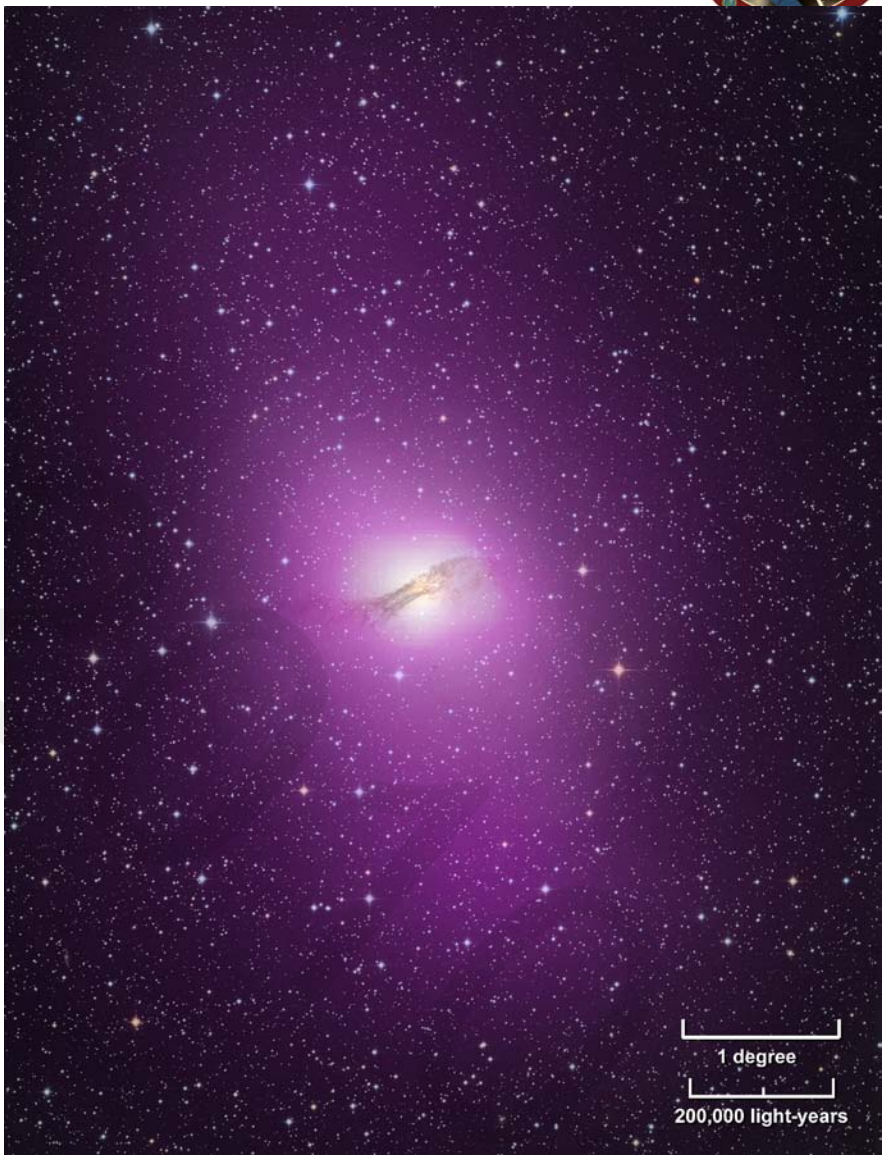
# LAT Radio Galaxies

- Confirmed EGRET detections of Cen A, NGC6251, 3C111
- LAT MeV/GeV discoveries of NGC1275/3C84, M87, 3C78, 3C120

- Discovery of giant lobes of Cen A (D=3.7 Mpc)

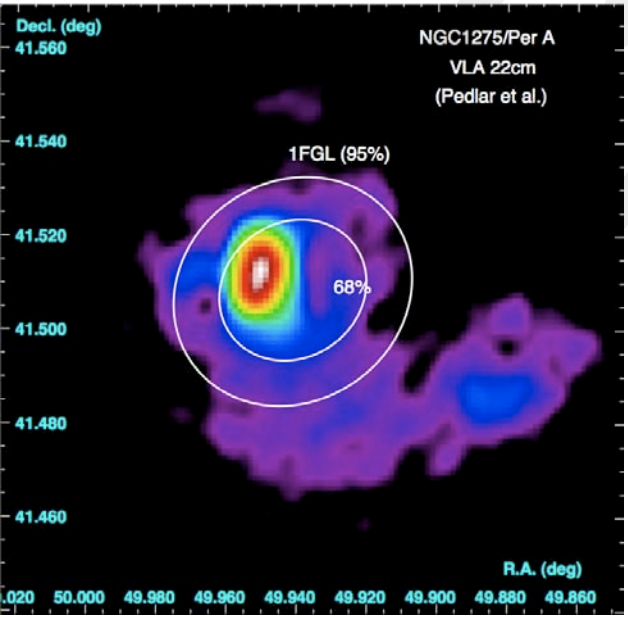
- Origin and location of γ-ray emitting region
- Emission Processes

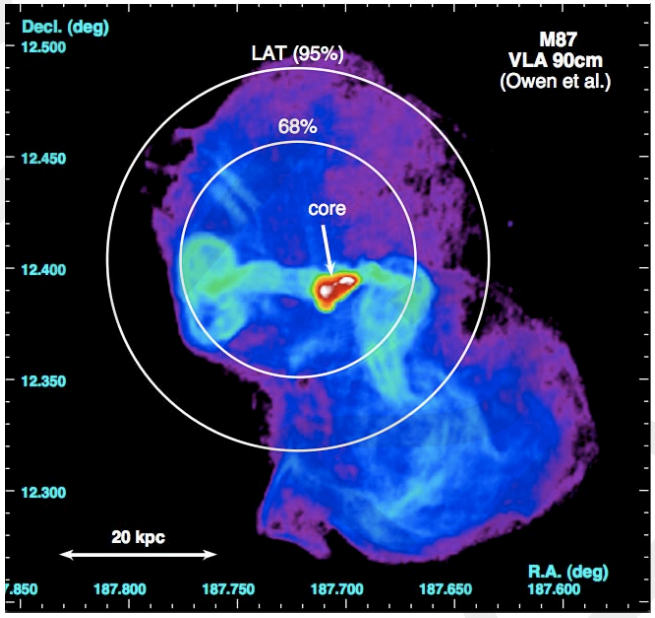
γ-ray color (purple) with optical galaxy

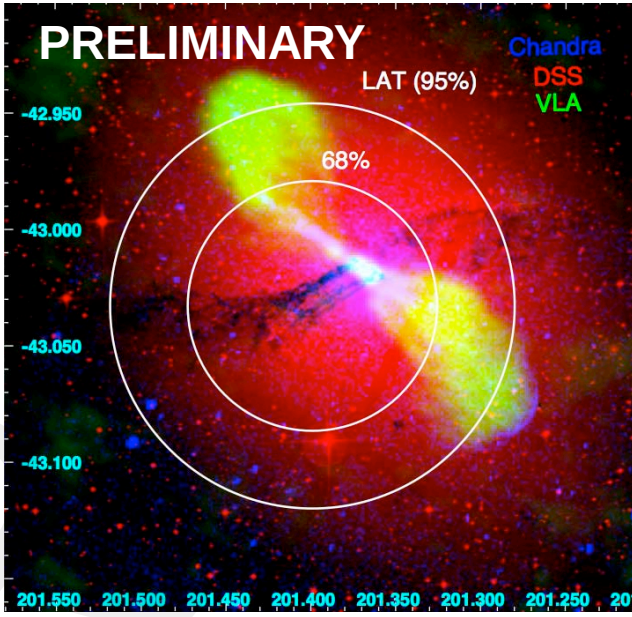


# LAT Associations: *Precise* γ-ray Localizations

- LAT γ-ray localizations, *radii* (95%) ~ 1.5 – 5 arcmin correspond to ~5-25 kpc for nearest radio galaxies

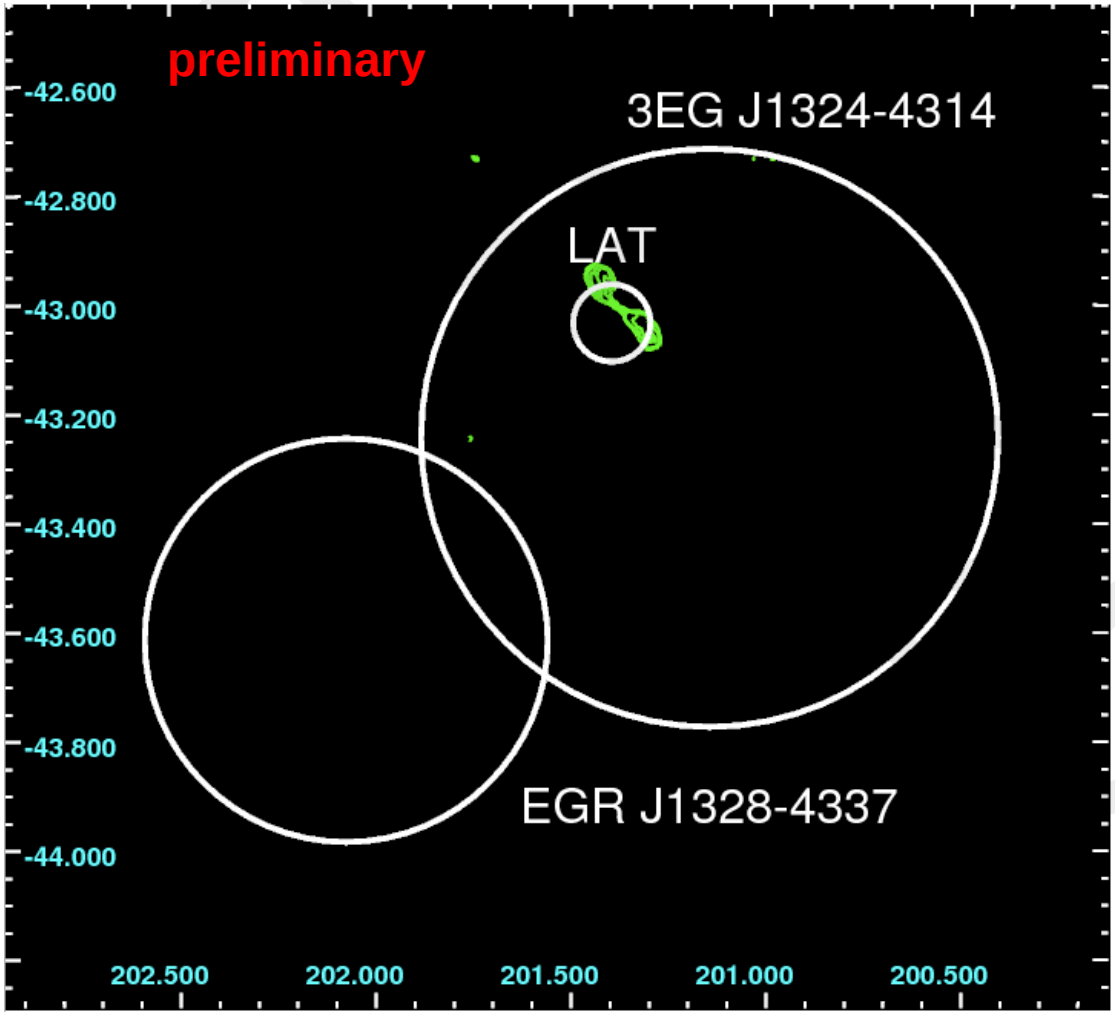



Pictured are LAT 68% and 95% confidence ellipses on radio images (+optical/X-ray in Cen A)

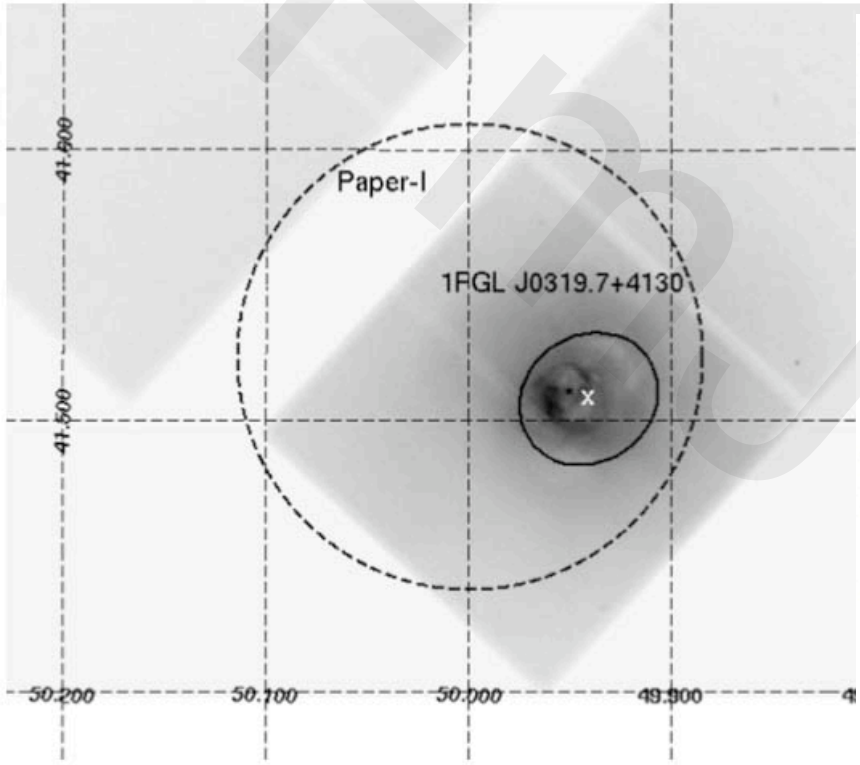
# LAT Detection of Cen A and Localization

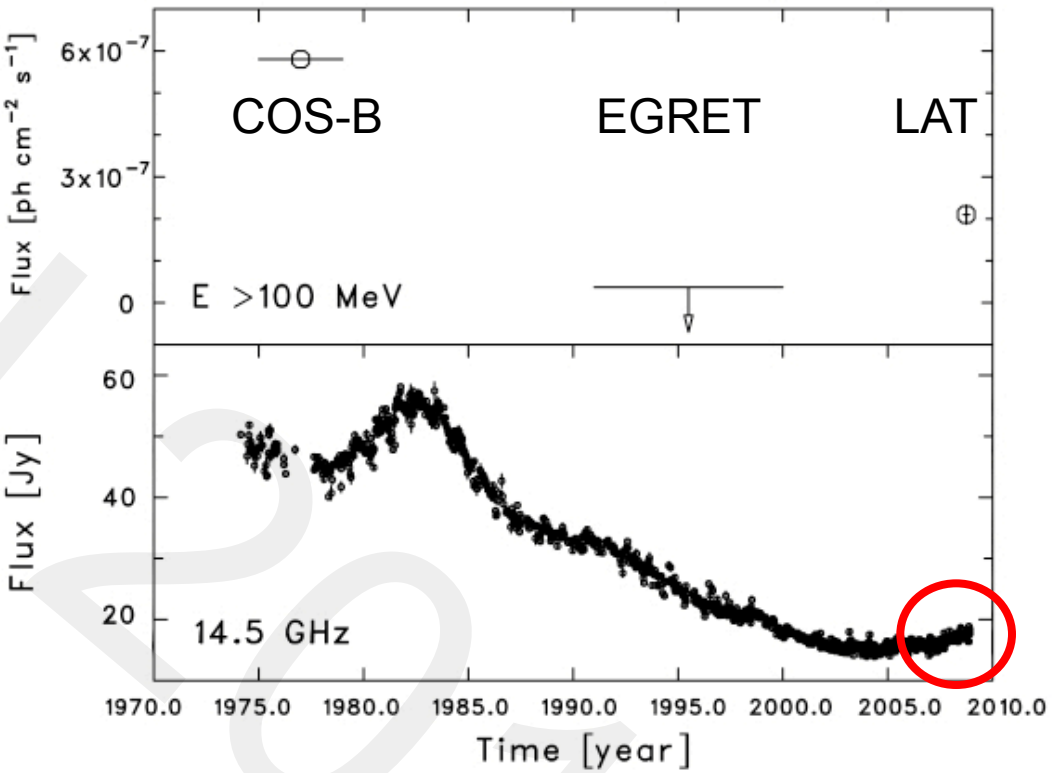



- Confirmed the 3EG source; EGR source displaced from Cen A
- LAT localization: r(95%)=0.071 deg; vast improvement over 3EG r(95%)=0.53 deg.

EGRET (Hartman et al. 1999); EGR (Casandijian & Grenier 2009)

# LAT Study of NGC 1275 = 3C84



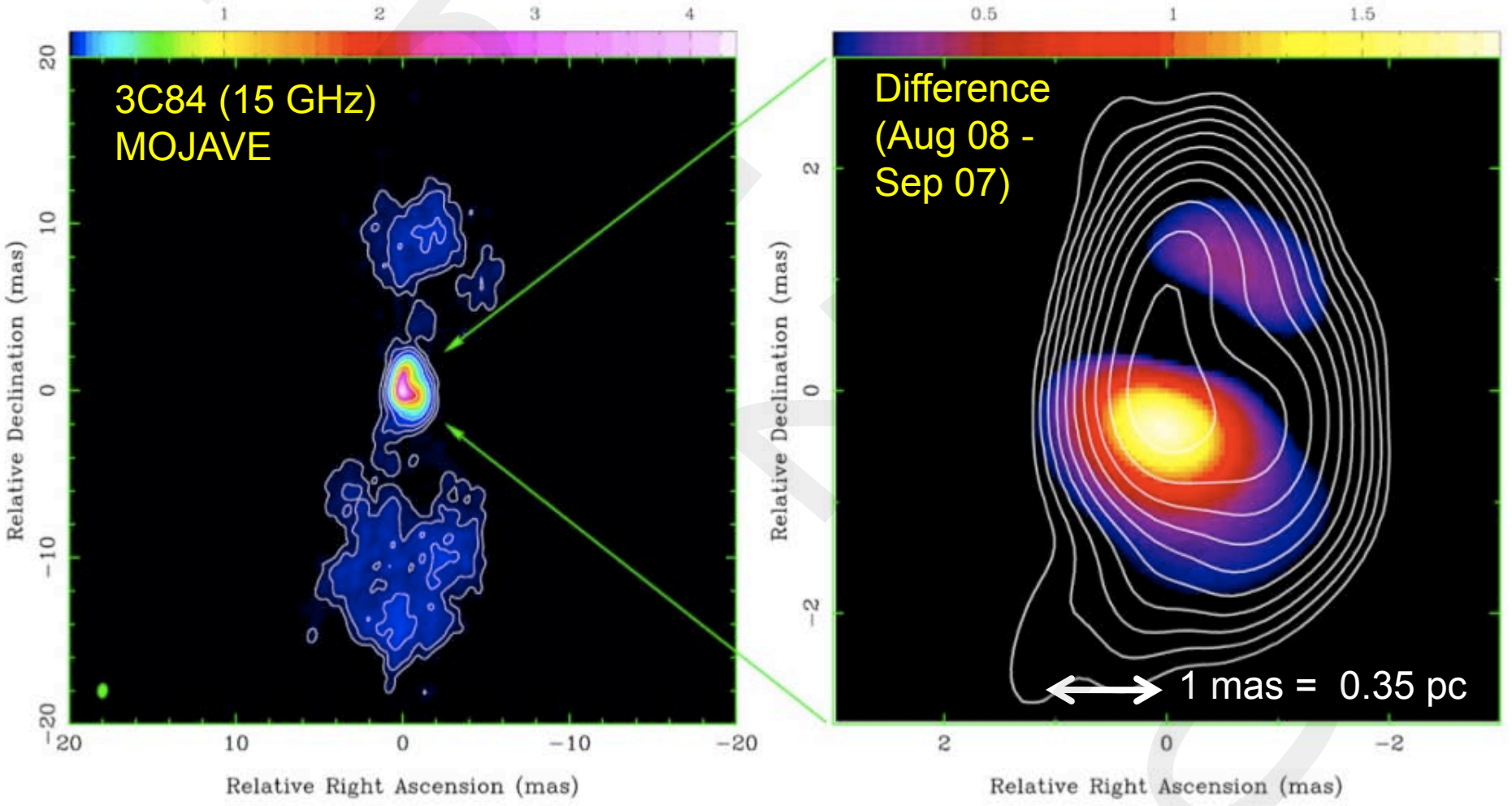

LAT 3-month & 11-month localizations

Long term gamma-ray and radio lightcurves

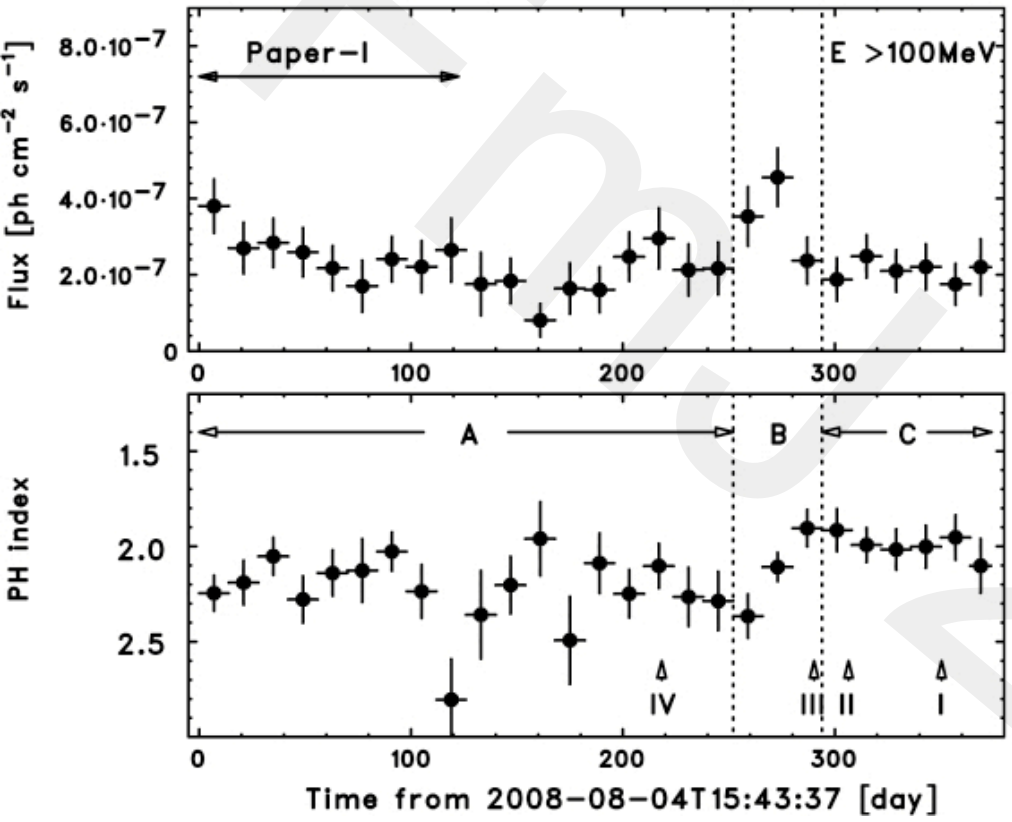
ApJ 2009, 699, 31: Lead: J. Kataoka, with MOJAVE
Acciari et al. 2009, 706, L275 (VERITAS+LAT)
Kataoka et al. 2010, 715, 554

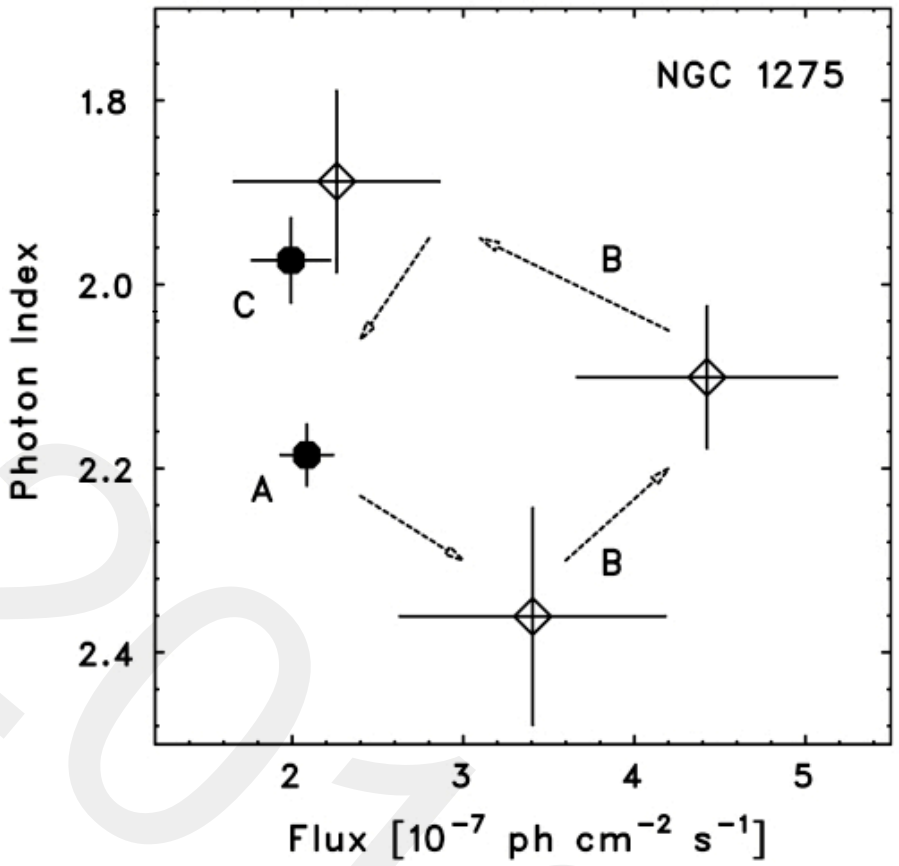
# 3C84 Flaring Radio (VLBI) Core

- Significant brightening of “core” in MOJAVE images simultaneous w/ Fermi



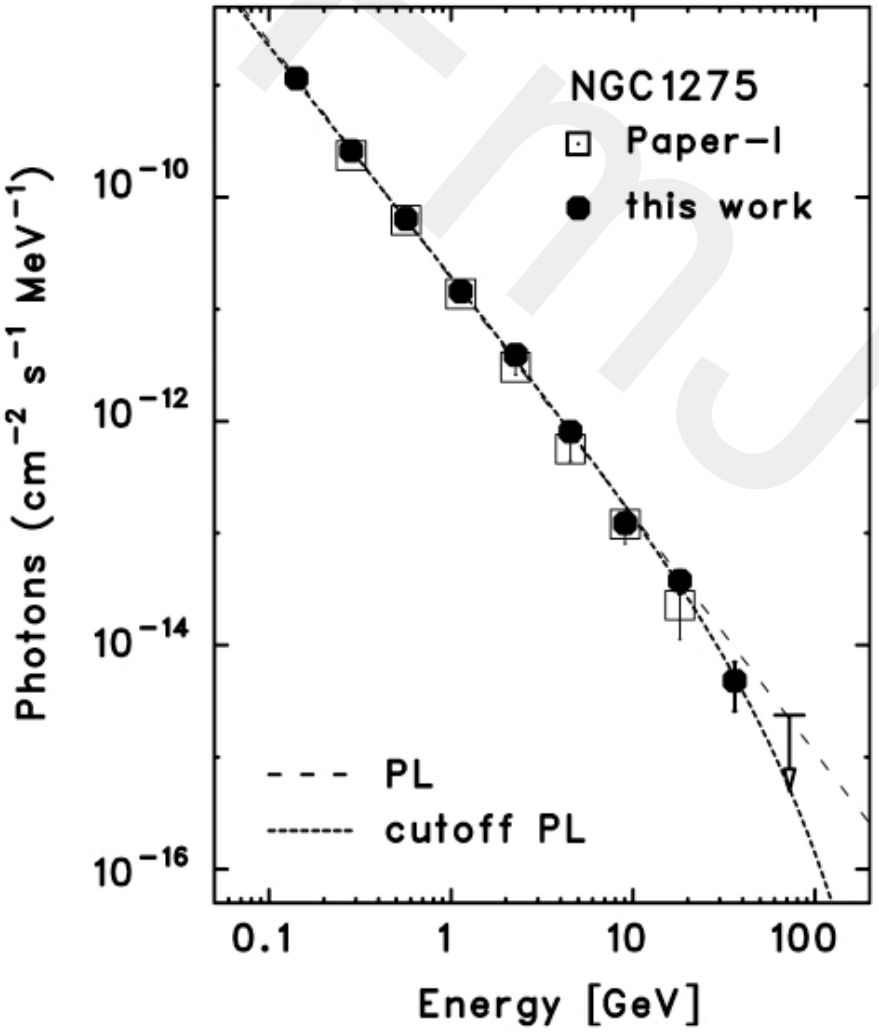
# NGC 1275: Utilizing all LAT Capabilities

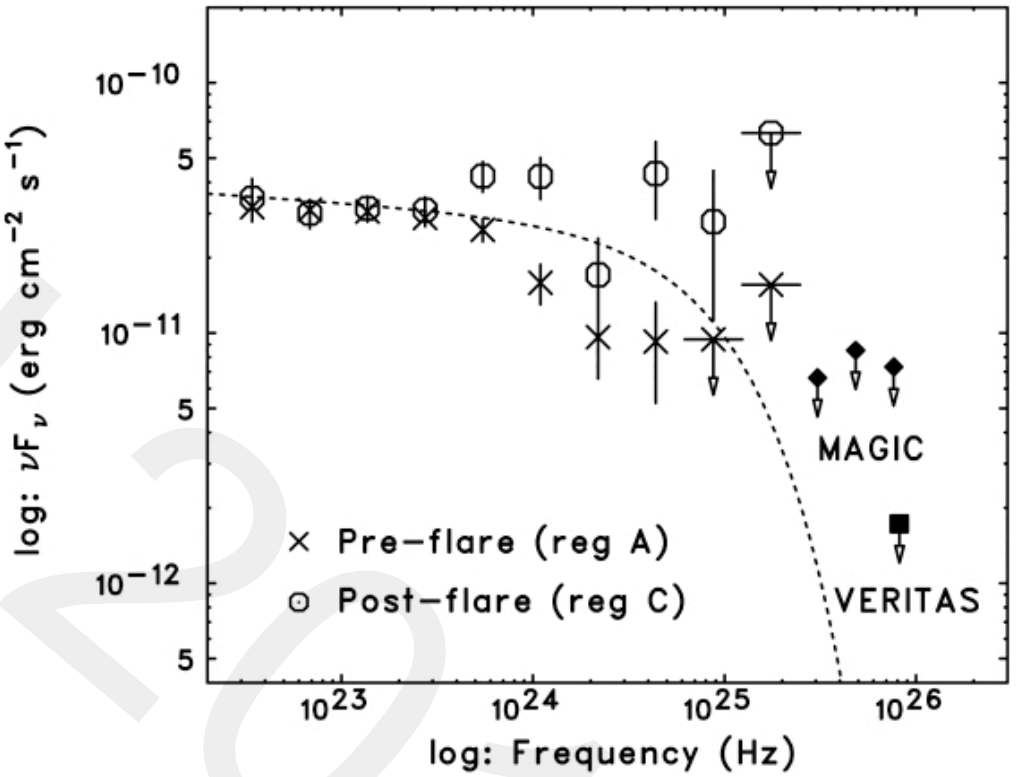



- Month-timescale flux doubling : ≈ 0.1 pc jet emission region
- Hysteresis loop behavior in Flux-Index plane through the flare

# NGC 1275: Spectral Curvature

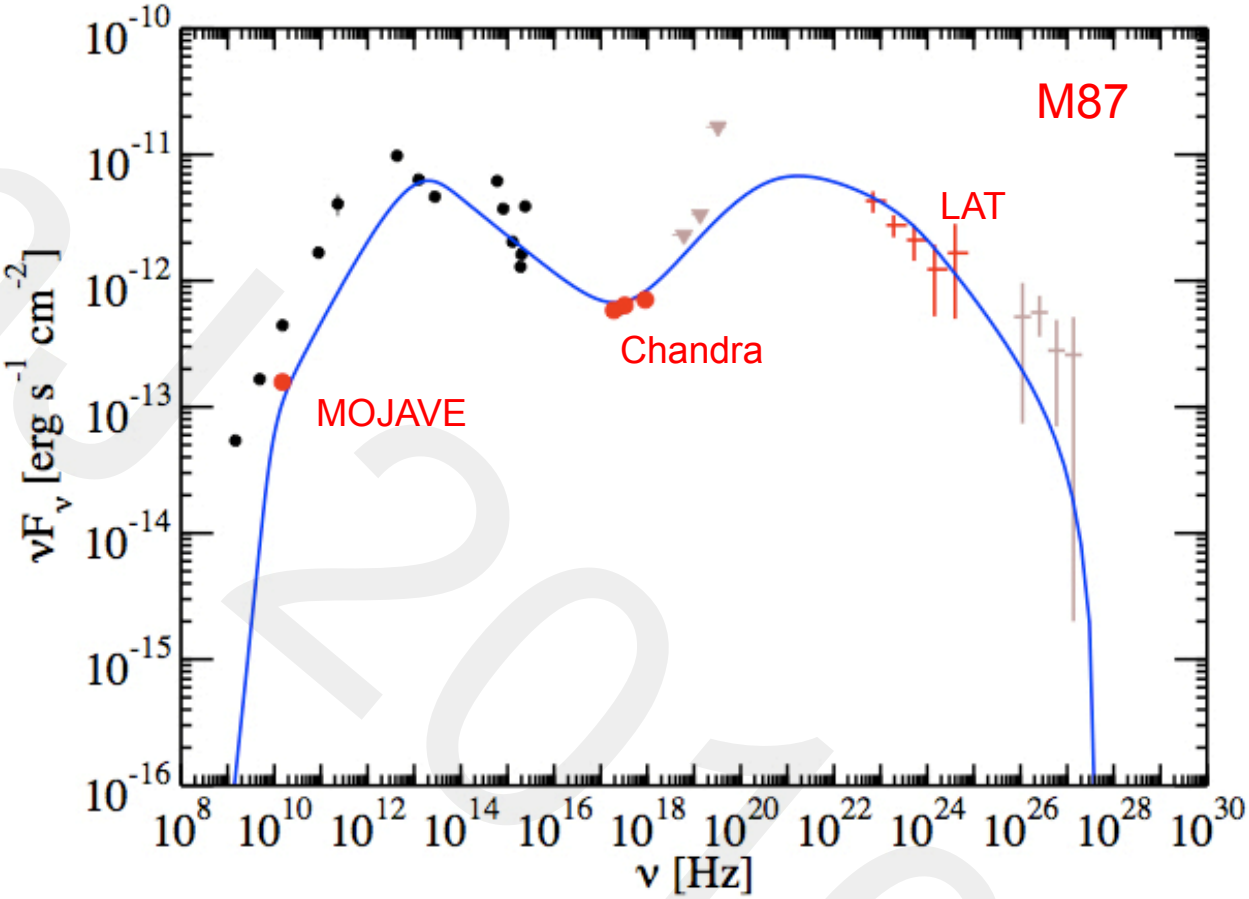



- LAT photons up to 30-70 GeV
- Spectral cutoff w.r.t. TeV points
- Hardening post-flare >GeV spectrum

# LAT in Context of Multi-λ SEDs

- MeV/GeV emission can be modeled as 1-zone synchrotron self-Compton with moderate jet beaming: δ~2-4
- Does not preclude other sources of GeV gamma-rays (outside the radio core)




ApJ 2009, 707, 55: Leads: Cheung, McConville
(recall Finke's talk for modeling of M87, Cen A, NGC1275)

# Site of GeV + TeV Emission in M87?

- 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 LAT, VLBA, and Chandra coverage

## VERITAS and MAGIC Report Flaring in Very High Energy Gamma Rays from M87

ATel #2542; *Rene A Ong (UCLA) for the VERITAS Collaboration; Mose Mariotti (U. Padova/INFN-Padova) for the MAGIC Collaboration*
*on 9 Apr 2010; 22:11 UT*
*Distributed as an Instant Email Notice (Request for Observations)*
*Password Certification: Rene Ong (rene@astro.ucla.edu)*

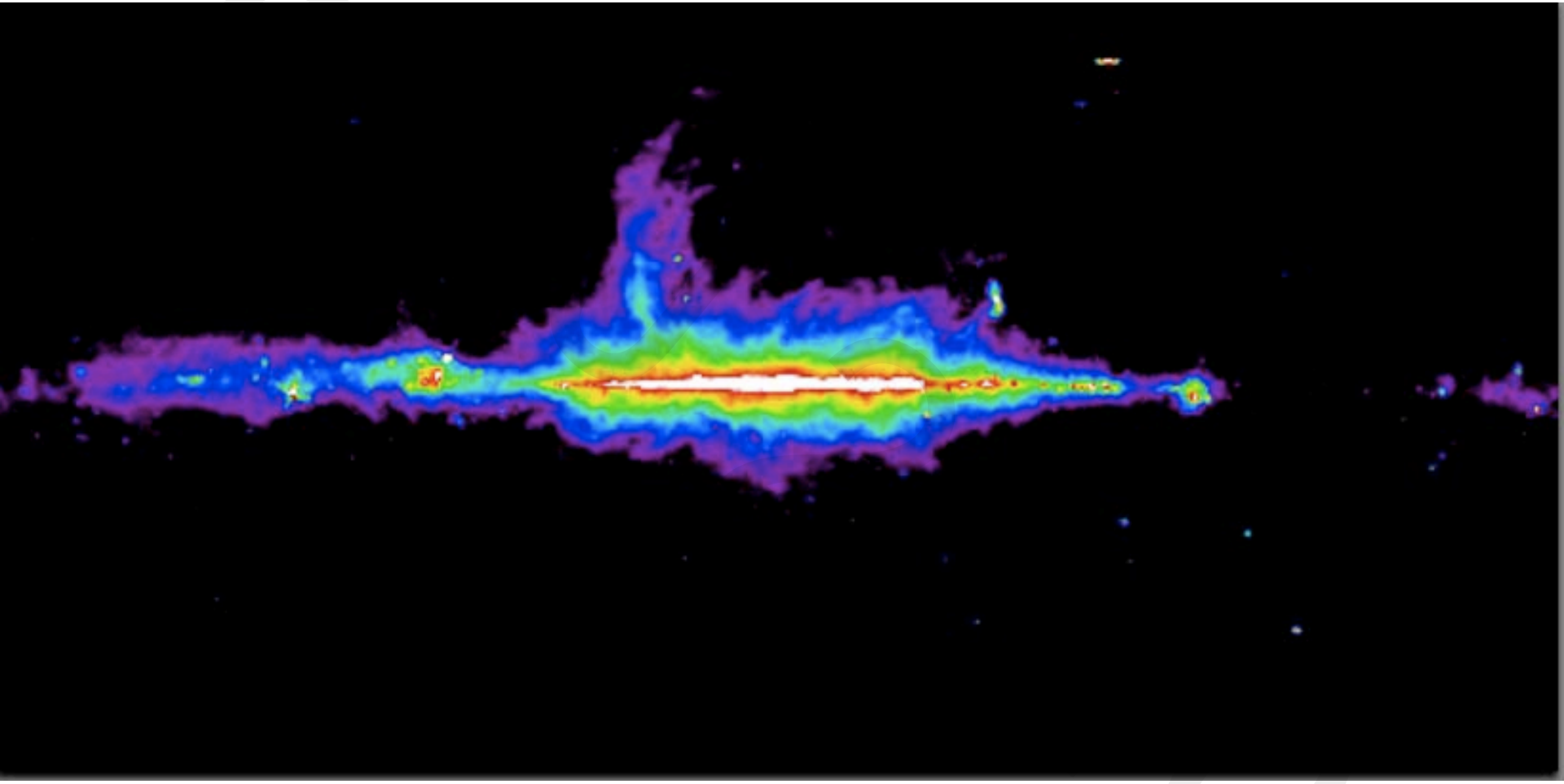
**Subjects: Gamma Ray, >GeV, Request for Observations, AGN**

We report a strong flare in very high energy (VHE; E > 100 GeV) gamma rays from the radio galaxy M87. M87 is being observed in a coordinated effort in 2010 by the ground-based VHE gamma-ray observatories VERITAS and MAGIC; this effort is a continuation of the joint monitoring program which was initiated by VERITAS, MAGIC, and HESS in 2008. An increasing VHE gamma-ray flux level has been measured over the past several nights (starting on MJD 55291), reaching a historic high state of about 20% of the flux of the Crab Nebula during last night's observations (MJD 55295). This flare follows a state of low average VHE flux from M87 over the past few months after a flare was reported by MAGIC at the beginning of 2010 (ATel #2431).

Observations by the VHE gamma-ray observatories will continue over the coming week. ToO observations with Chandra and the VLBA have been triggered. Observations at other wavelengths are encouraged.

VERITAS is an array of four atmospheric Cherenkov telescopes, located on Mt. Hopkins, Arizona, USA. MAGIC is a system of two atmospheric Cherenkov telescopes, located on the Canary Island of La Palma, Spain. Questions regarding the VERITAS observations should be directed to Rene Ong (rene@astro.ucla.edu). Questions regarding the MAGIC observations should be directed to Mosè Mariotti (mariotti@pd.infn.it).

# Cen A the Radio Galaxy



All-sky 408 MHz (Haslam et al. 1982)

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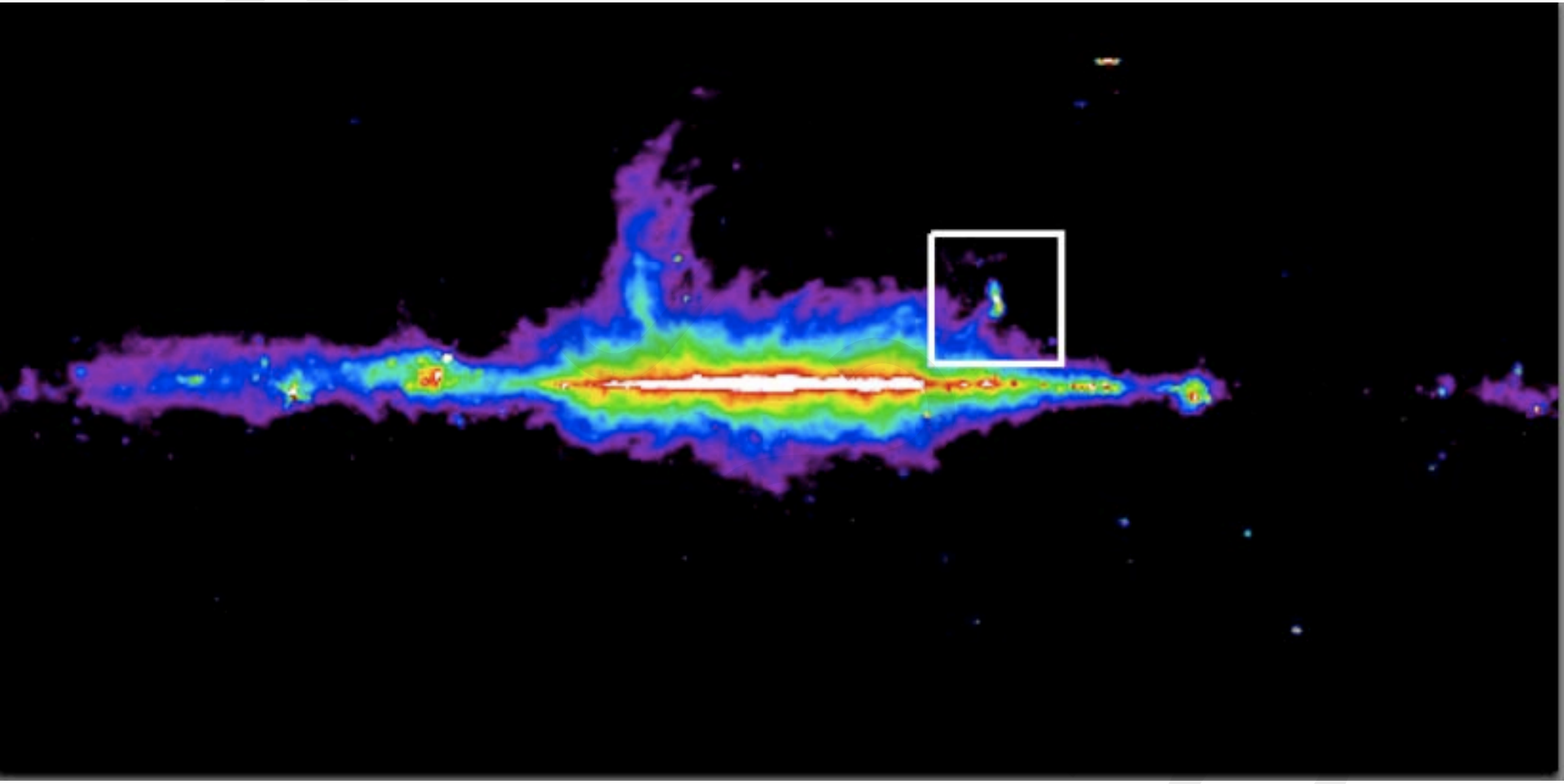

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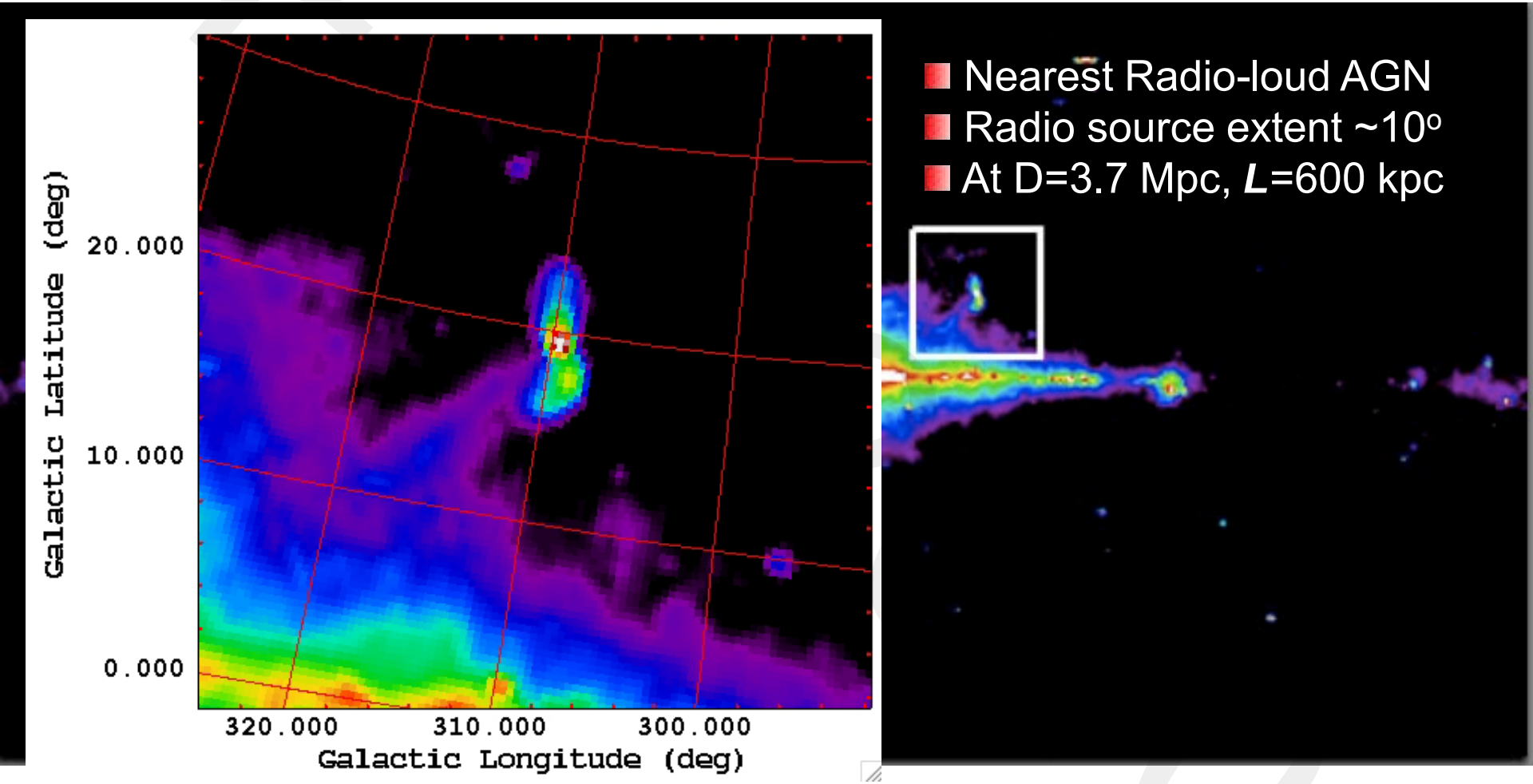


- Nearest Radio-loud AGN
- Radio source extent ~10$^{o}$
- At D=3.7 Mpc, ***L***=600 kpc

All-sky 408 MHz (Haslam et al. 1982)

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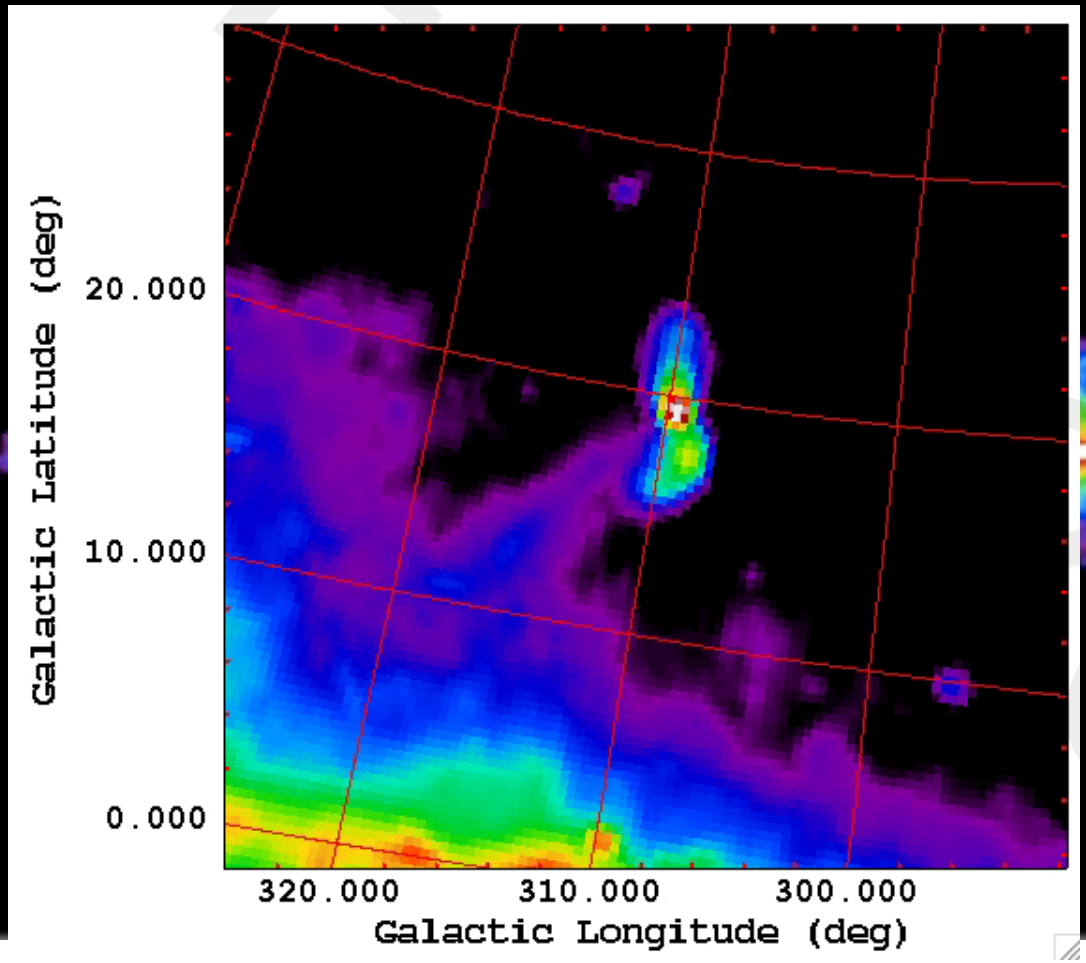


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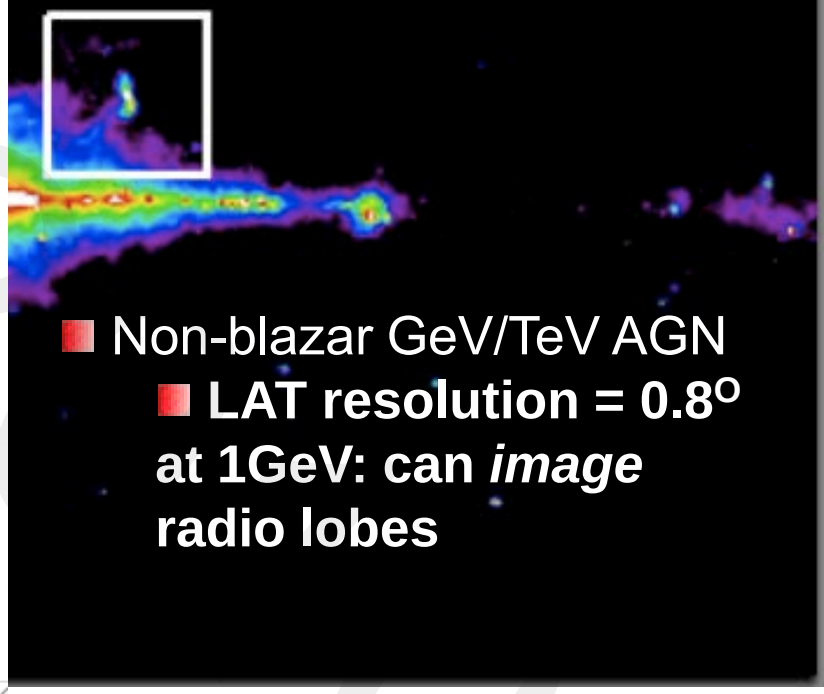
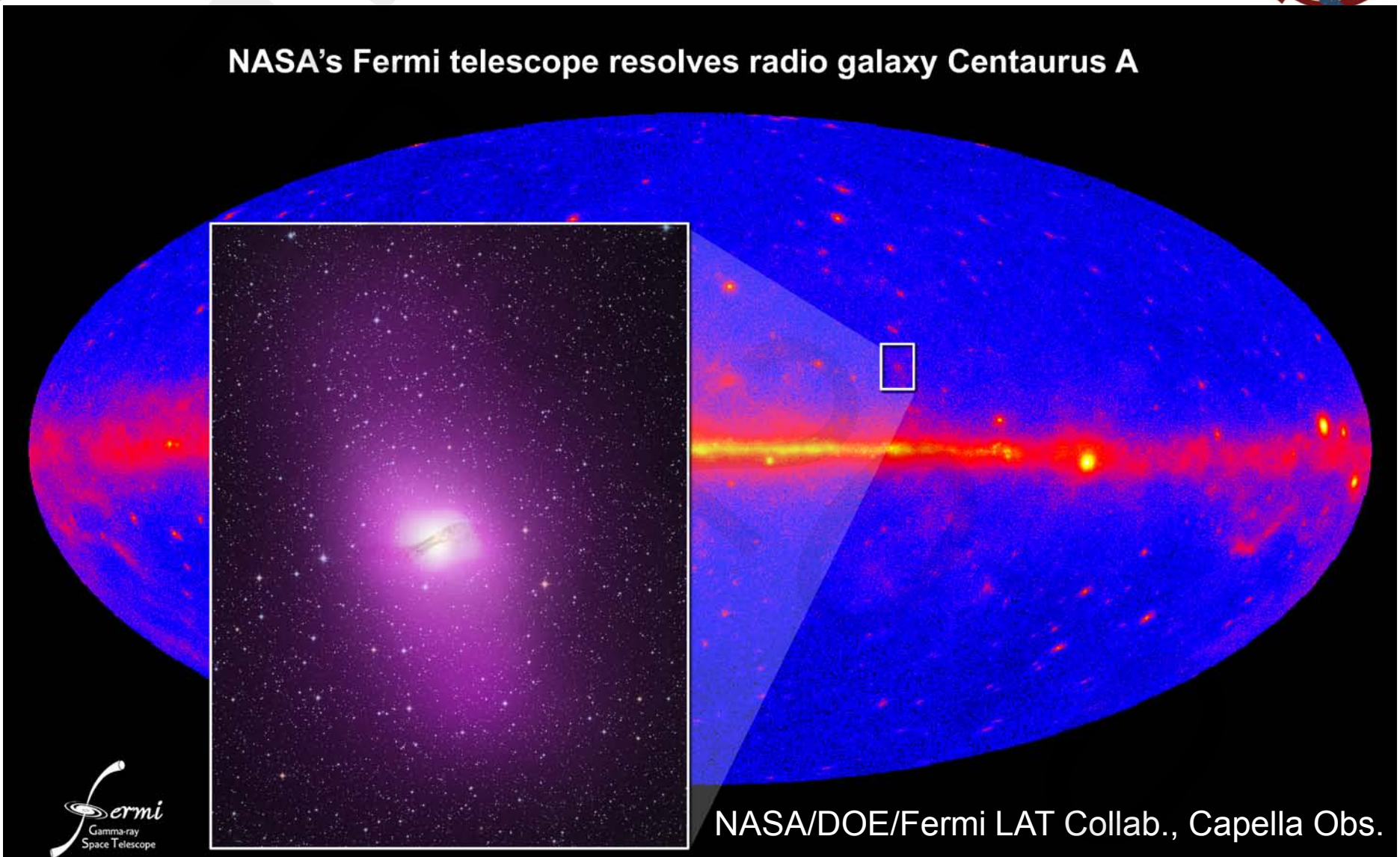


- Non-blazar GeV/TeV AGN
  - **LAT resolution = 0.8$^{o}$ at 1GeV: can *image* radio lobes**

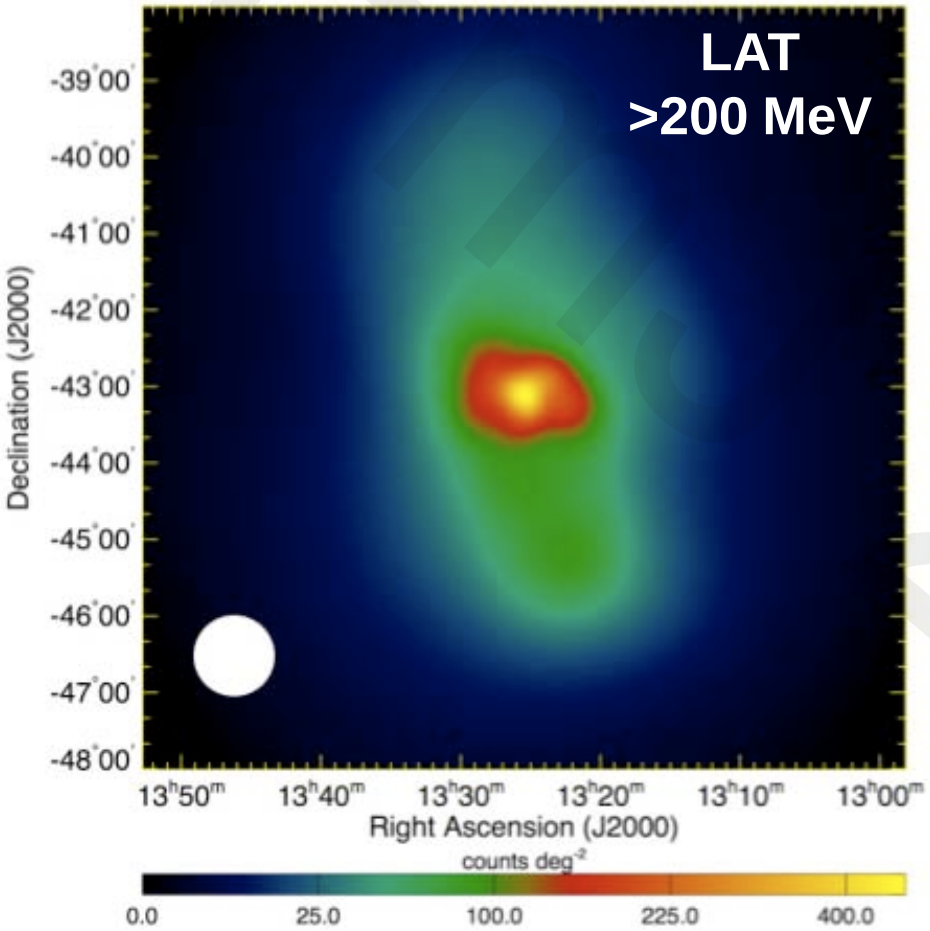
All-sky 408 MHz (Haslam et al. 1982)

# Cen A the Gamma-ray Galaxy

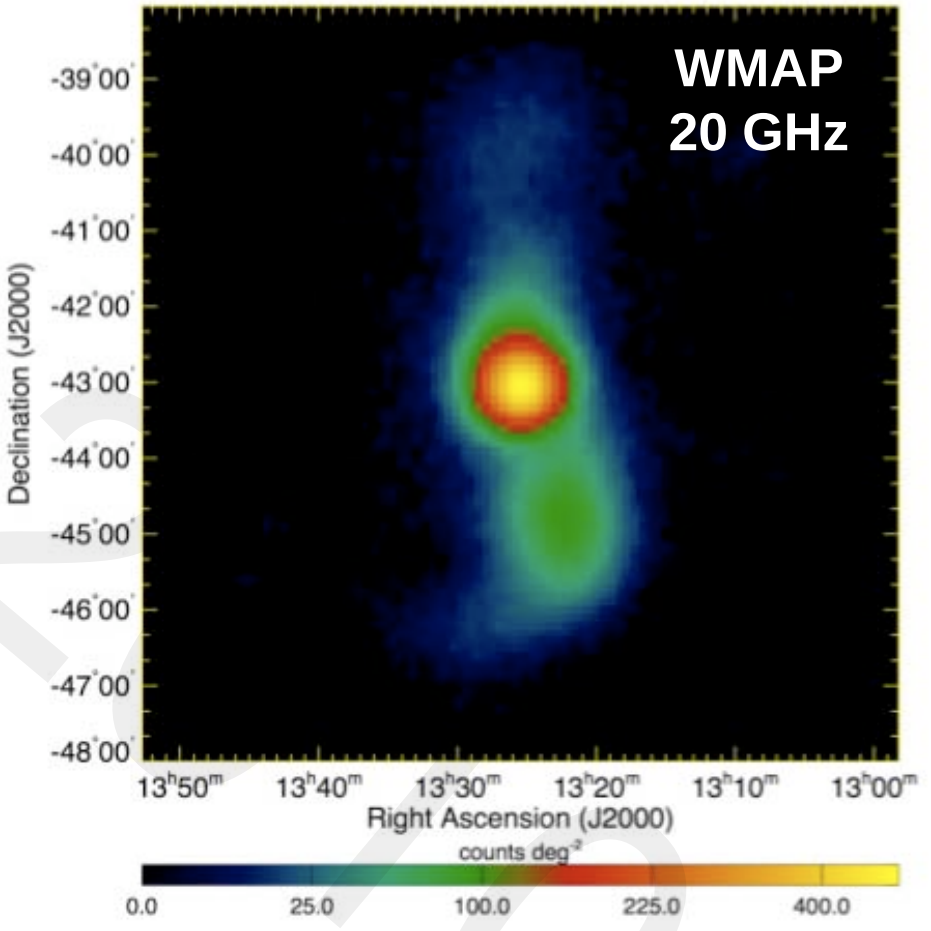


# First γ-ray Imaging of Radio Galaxy Lobes

## Over ½ of the total >100 MeV observed LAT flux in the lobes



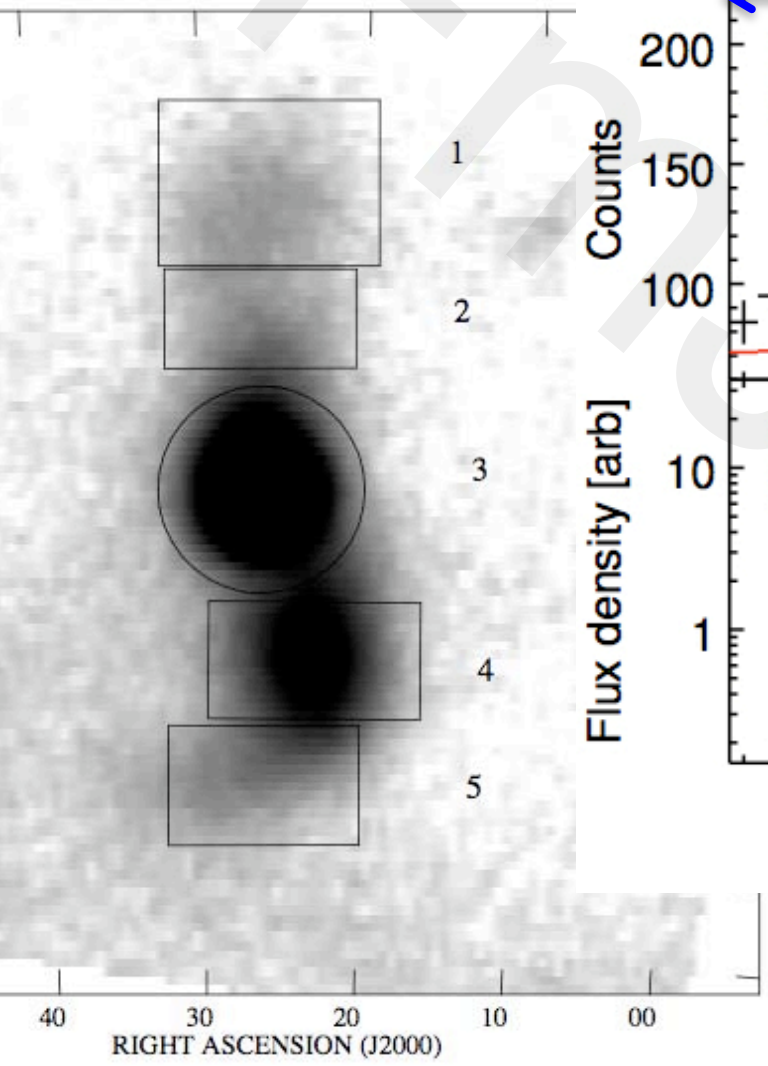

Background & point sources subtracted

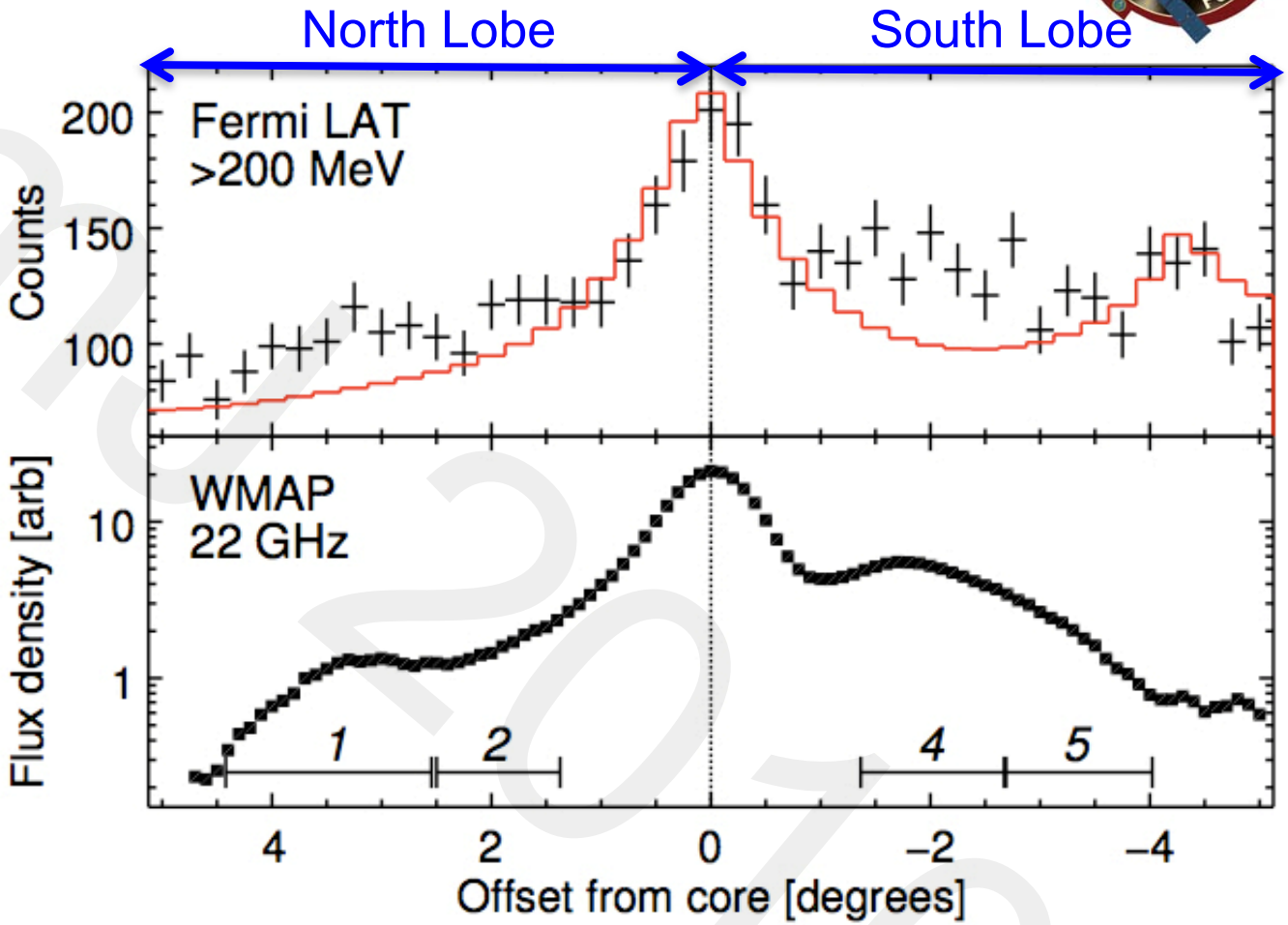



From Nils Odegard (GSFC)

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

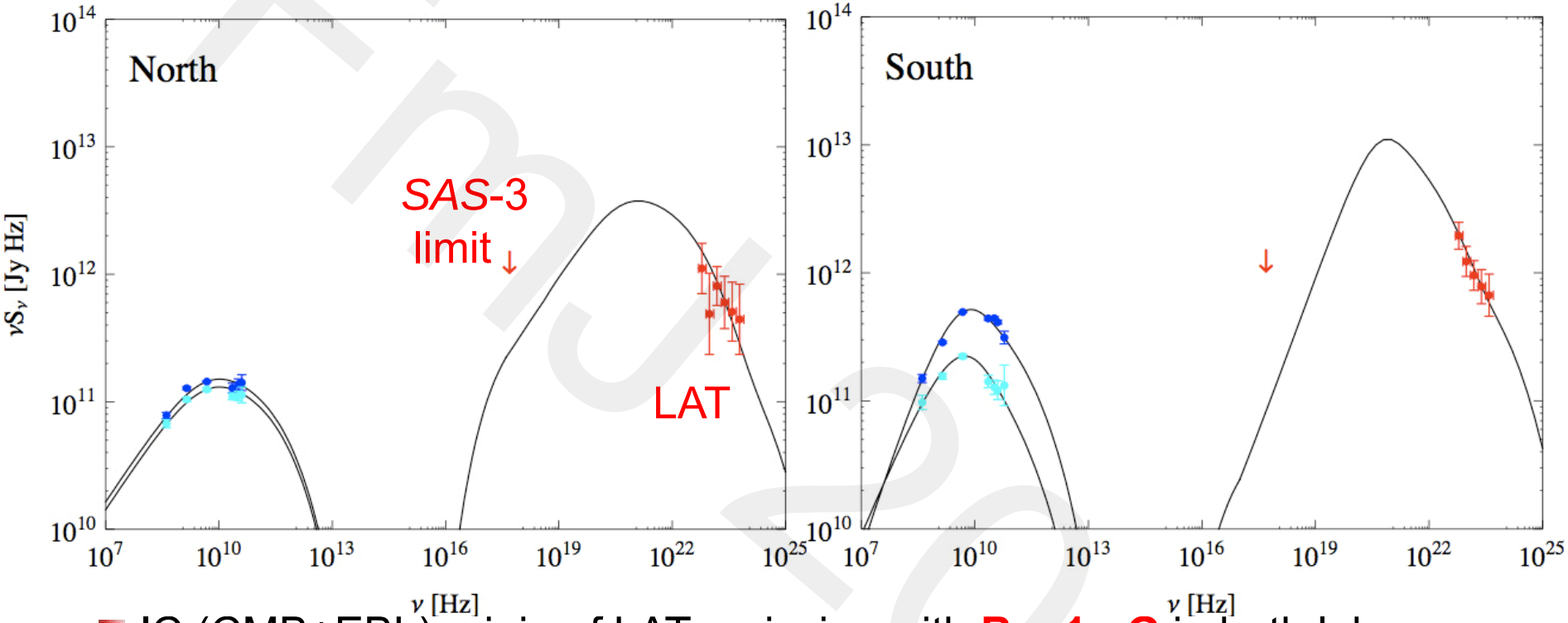
# Gamma-ray and Radio Counts Profiles



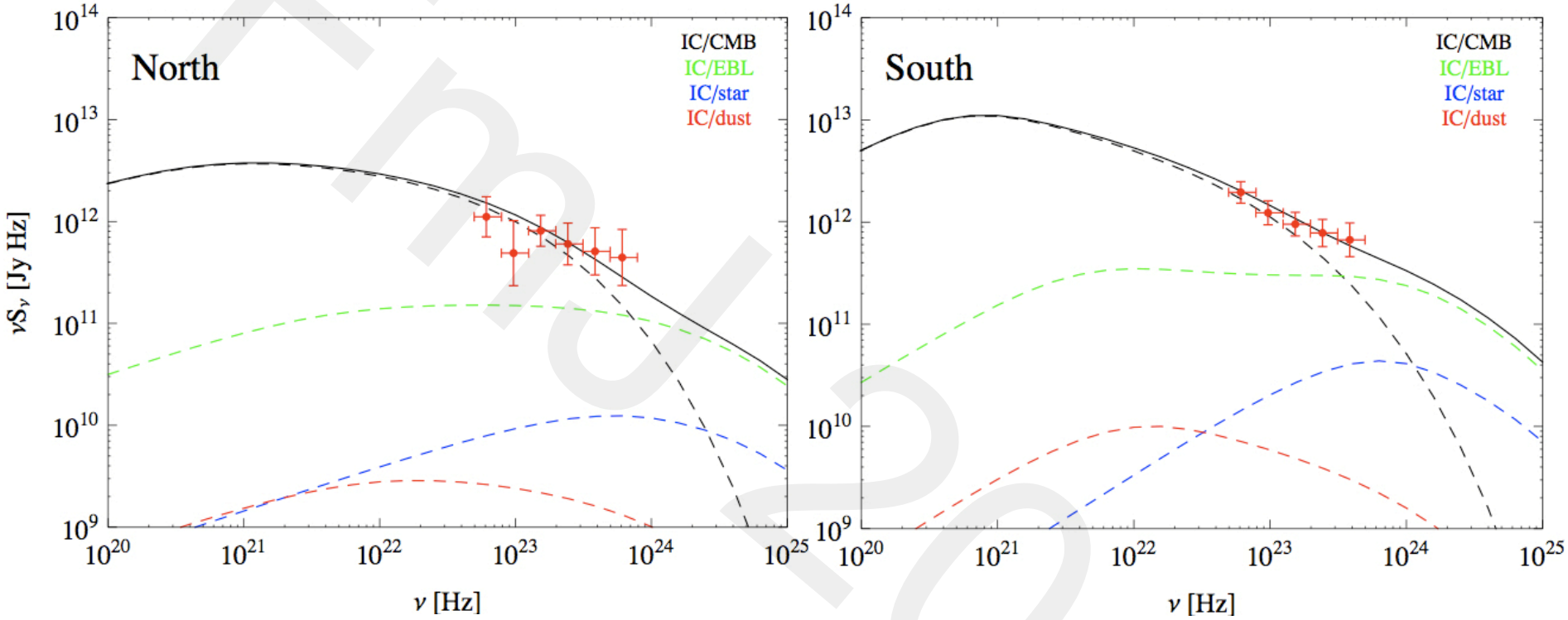

Regions 1 & 2 (north) and 4 & 5 (south) as defined in prediction paper Hardcastle, Cheung, Feain, Stawarz 2009

# Imaging Inverse Compton γ-ray Emission



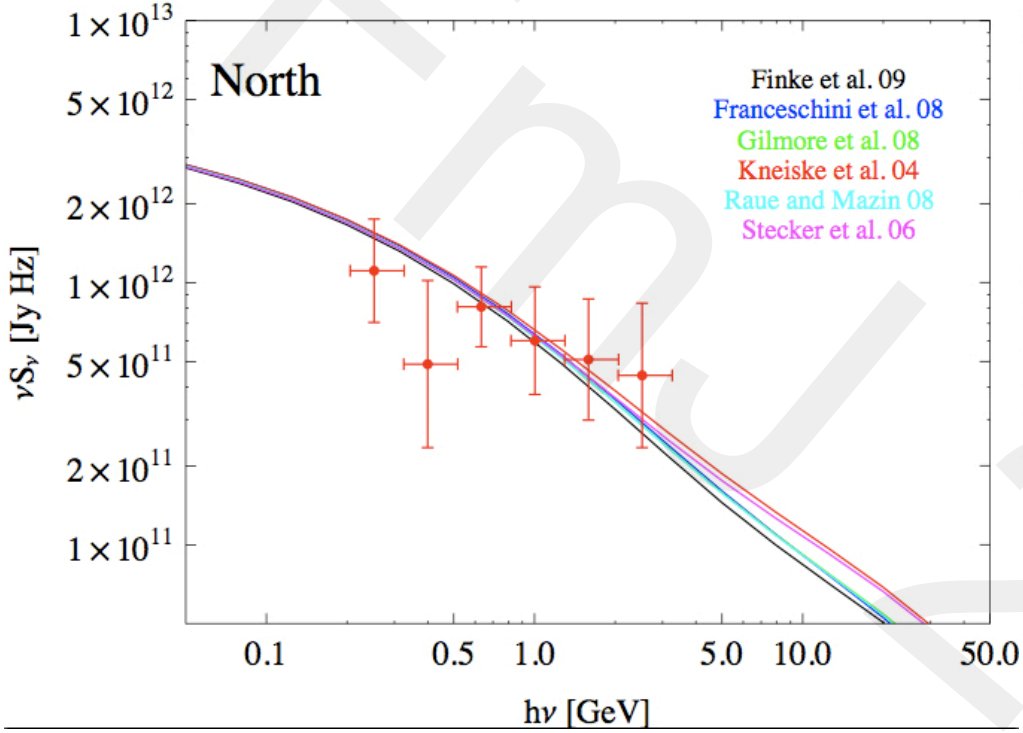

- IC (CMB+EBL) origin of LAT emission with **B ~ 1 μG** in both lobes, near equipartition
- IC component dominant, $U_{CMB}/U_B$ **~ 10** -- 'requires' the lower *B*-field in Cen A lobes than typical in other (more powerful) examples
- **First inverse Compton lobe measurements in γ-rays!**

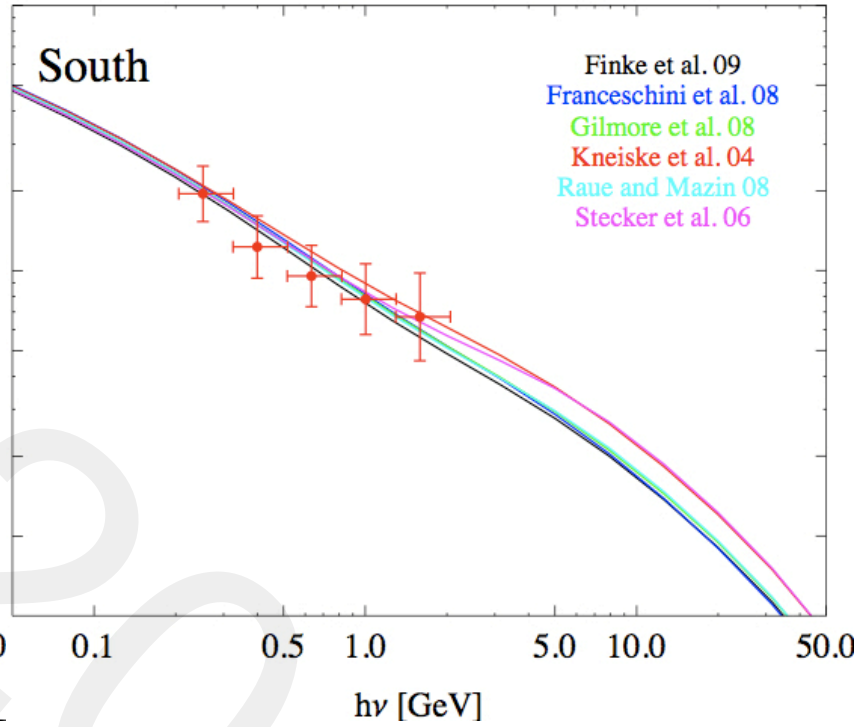
# Inverse Compton Emission: Close-up




- LAT γ-ray emission dominated by IC/CMB component for the modeled electron energy spectra (broken power-law + exponential)
- Can uniquely probe EBL which dominates here at higher-energies, >GeV (cf., Georganopoulos et al. 2008 for Fornax A)
- Host galaxy + dust components negligible at >100's kpc from center

# Inverse Compton Emission: Close-up

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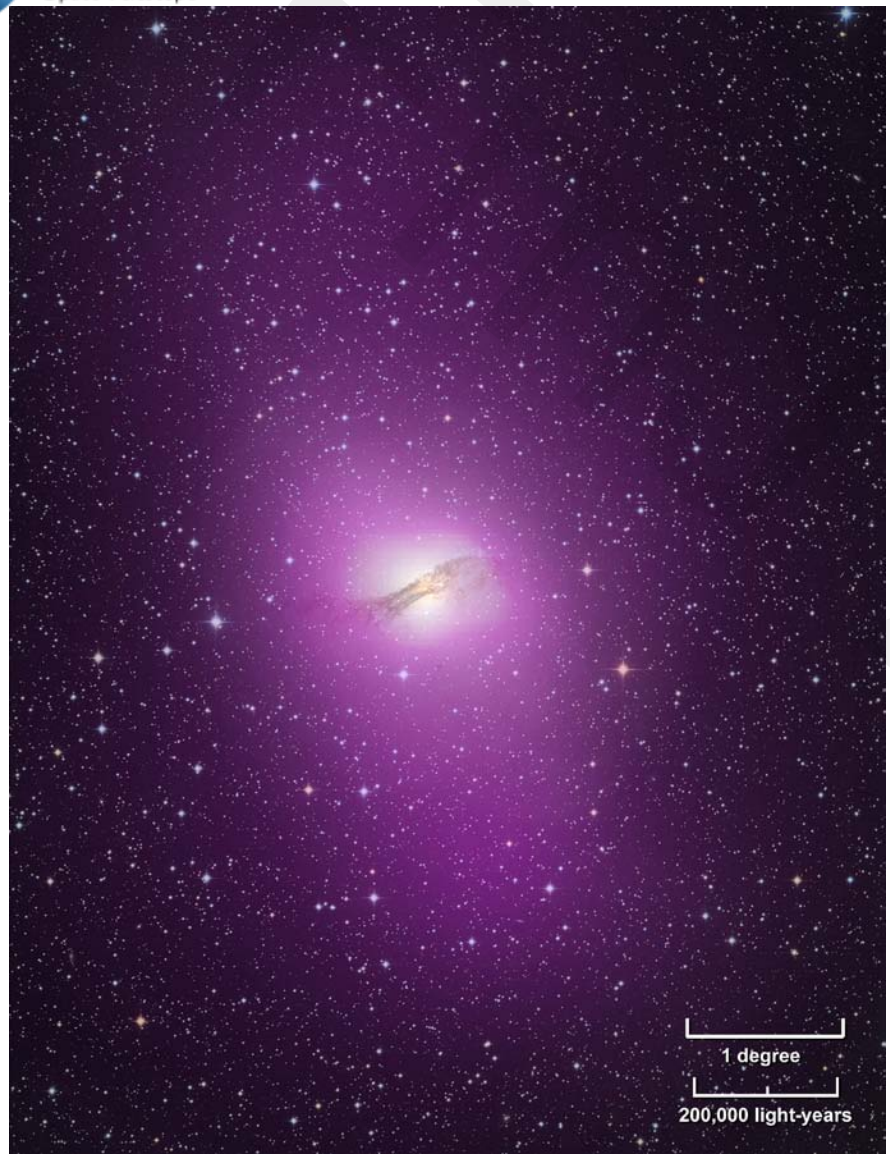
# Cen A Summary




- Confirms pre-launch expectation that radio lobes can produce **inverse Compton γ-ray emission**
- Cen A is (uniquely) large enough ~10° to directly image with Fermi-LAT
- Require 0.1-1 TeV electrons in giant 'relic' lobes: accelerated in-situ or efficient transport from center
- Estimate $E_{tot}$ = $10^{58}$ erg, jet power ~$10^{43}$ erg $s^{-1}$ (~$10^{-3}$ $L_{edd}$), non-thermal/thermal plasma pressures comparable
- Implication for emission region/mechanism in LAT radio galaxies?

NASA/DOE/Fermi-LAT Collab., Capella Obs.

# Summary

- Systematic studies of relativistic jets with larger-range of viewing angles now possible with Fermi-LAT
- Arcminute-level localizations to pinpoint γ-ray sources (compare to typical ½ degree level for EGRET)
- Accurate ~0.1-100 GeV spectra in MWL context
- All-sky monitoring to detect flaring emission – constraints on emission region size and location
- "Non-blazar" gamma-ray lobes: Cen A, 4C+55.17 young radio galaxy?
- More to come in 2FGL and beyond