Characteristics of Gamma-ray Loud Blazars in VIPS

Justin Linford, UNM
November 5, 2010

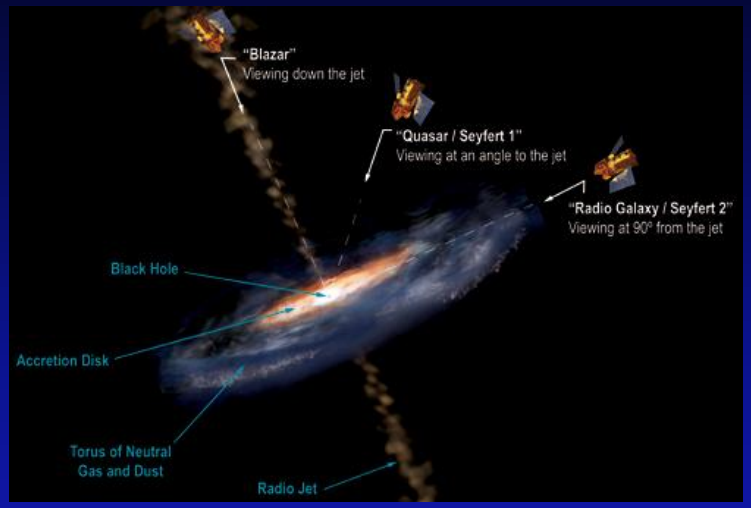
Collaborators:
Gregory Taylor (UNM)
Roger Romani & Stephen Healey (Stanford)
Joseph Helmboldt (NRL)
Anthony Readhead, Rodrigo Reeves, & Joseph Richards (Caltech)
Garret Cotter (Oxford)

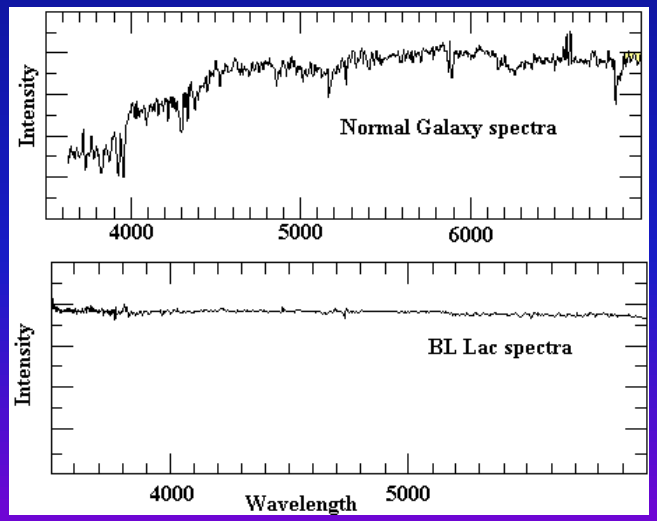
painting by Don Dixon
for "Scientific American"

THE UNIVERSITY of NEW MEXICO

Blazars

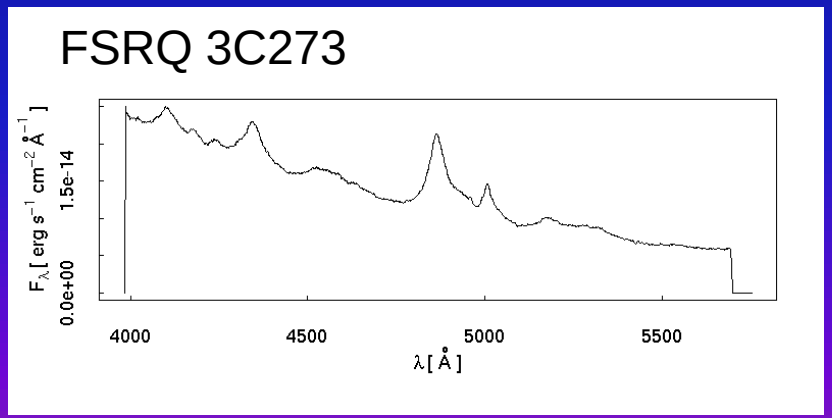
NASA





Siobahn Morgan, UNI

- AGN with one jet pointed nearly straight at us
- High variability
- Typically one-sided jet
- Apparent superluminal motion in the jet
- Two types:
  - BL Lacs
  - FSRQs



Koratkar & Blaes 1999

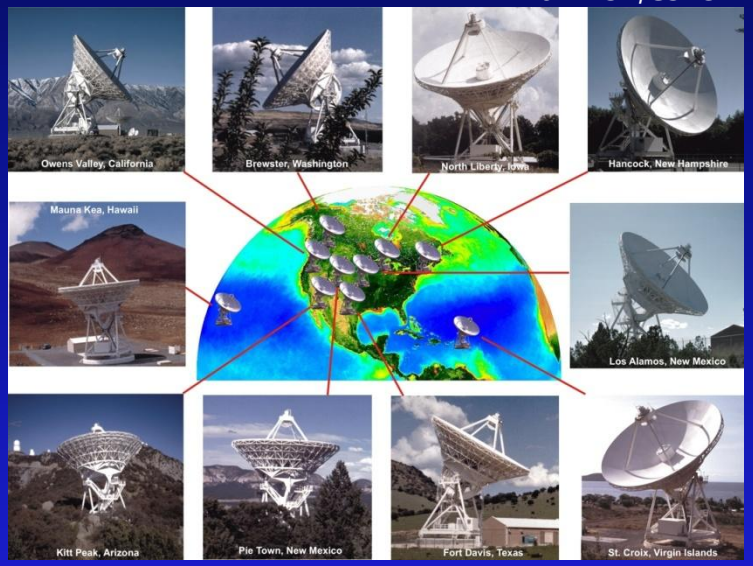
The Tools: Fermi & VLBI

- The Fermi Gamma-ray Space Telescope
  - Large Area Telescope (LAT)
  - Wide-field
  - Covers ~20 MeV to 300 GeV

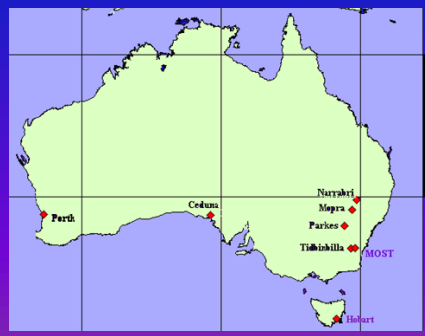
NASA

- VLBI

NRAO/AUI & NASA/GSFC



Paul Boven & NASA



Tasso Tzioumis, ATNF

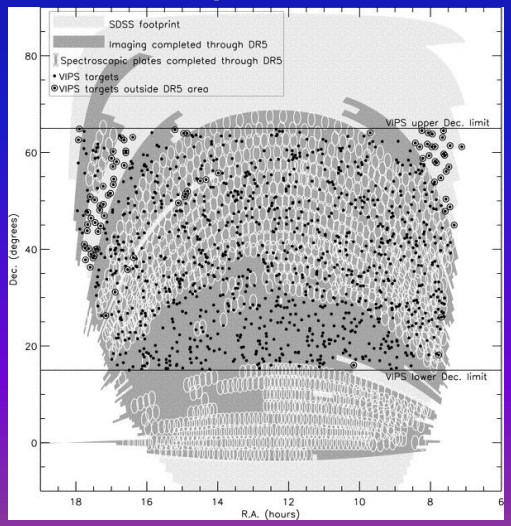
What others have found: Correlation & Polarization

- Previous studies have reported a link between radio flux density and gamma-ray flux.
  - Kovelev et al. (2009) using MOJAVE sources, Ghirlanda et al. (2010) using the ATCA, and The LAT team (Abdo et al. 2009) using older VLBA data.
- Other experiments have noted the abundance of polarized sources among the LAT sample.
  - Hovatta et al. (2010), using MOJAVE data, reported that the median fractional polarization for LAT sources was higher than for non-LAT sources.
  - They also found that the polarization levels of LAT sources was stronger during the LAT detections than in previous years, but only by a factor of 1.2.

Our Sample

- VIPS: VLBA Imaging and Polarimetry Survey (Helmboldt et al. 2007)
- 1127 sources
- 5 GHz (6 cm)
- Also have 8.5 GHz (3.5 cm) VLA flux densities for all sources (CLASS, Myers et al. 2003).

http://www.phys.unm.edu/~gbtaylor/VIPS/

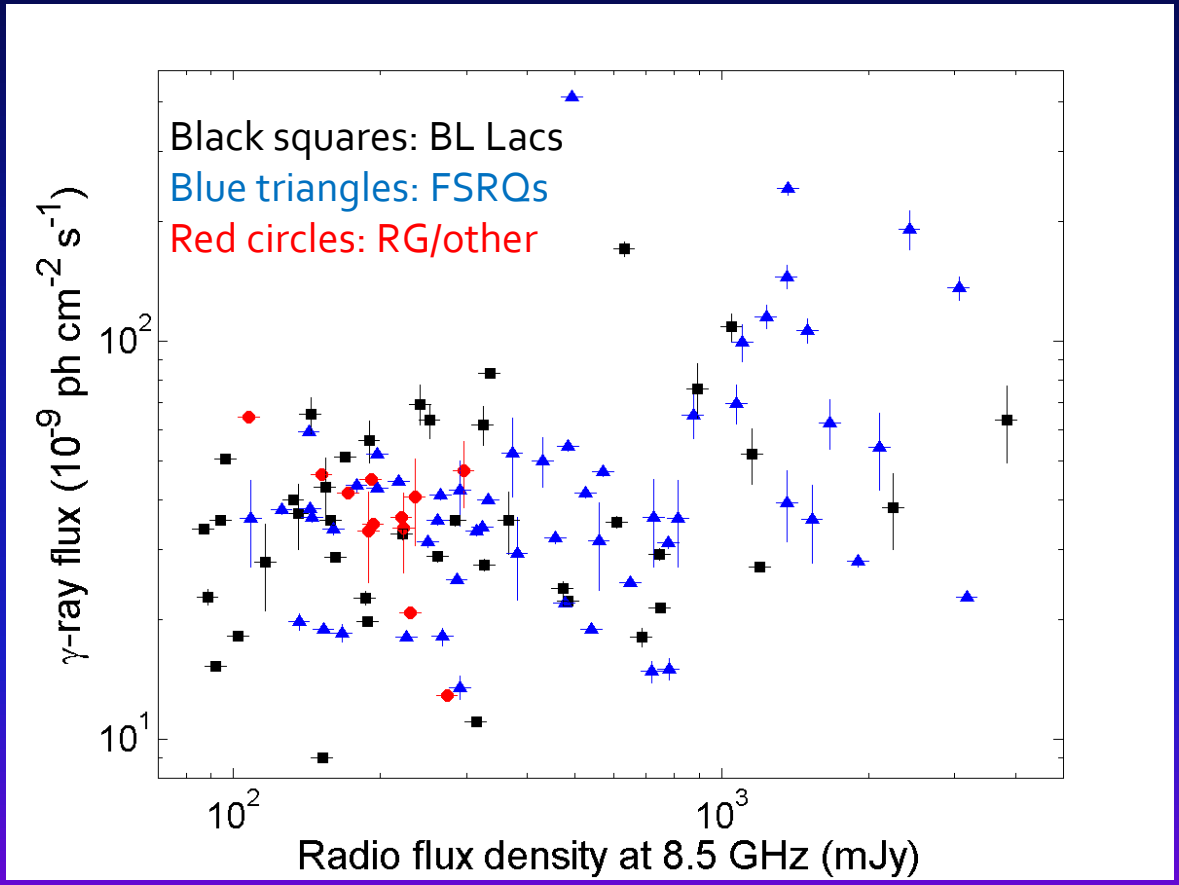


- 109 LAT-detected sources
  - 102 VIPS sources
  - 7 MOJAVE sources (15 GHz)
  - 41 BL Lacs, 56 FSRQs, 12 RG/other
- 1018 non-LAT VIPS sources
  - 24 BL Lacs, 479 FSRQs, 515 RG/other
- **Note:** 63% of the VIPS BL Lacs are gamma-ray loud, compared to only about 9% of the VIPS FSRQs

THE UNIVERSITY of NEW MEXICO

Flux-Flux Correlation Results

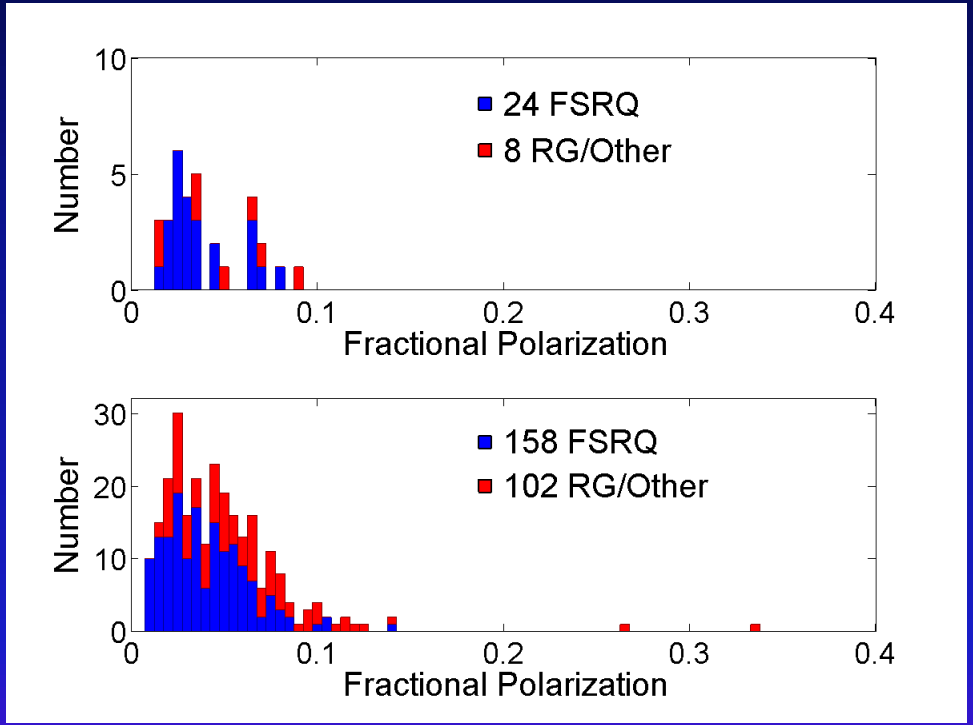
- BL Lacs
  - Rho = 0.217
  - P = 0.17
  - No correlation
- RG/Other
  - Rho = -0.413
  - P = 0.16
  - No correlation
- FSRQs
  - Rho = 0.318
  - P = 0.017
  - Correlation



LAT fluxes: 100 MeV – 100 GeV

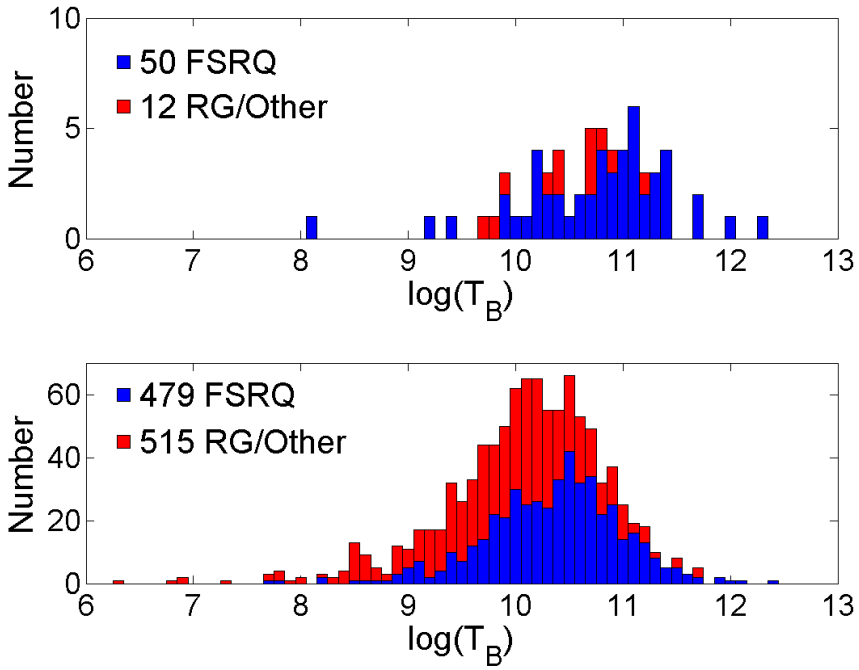
Core Polarization

- LAT sources are more likely to be polarized.
  - LAT: 49/102
  - Non-LAT: 270/1018
- Fractional polarization is slightly less for LAT sources.
  - LAT median: 3.5%
  - Non-LAT median: 4.4%
  - This is different from other studies (e.g. Hovatta et al. 2010)



Stacked histograms
Top: LAT
Bottom: non-LAT

Core Brightness Temperatures

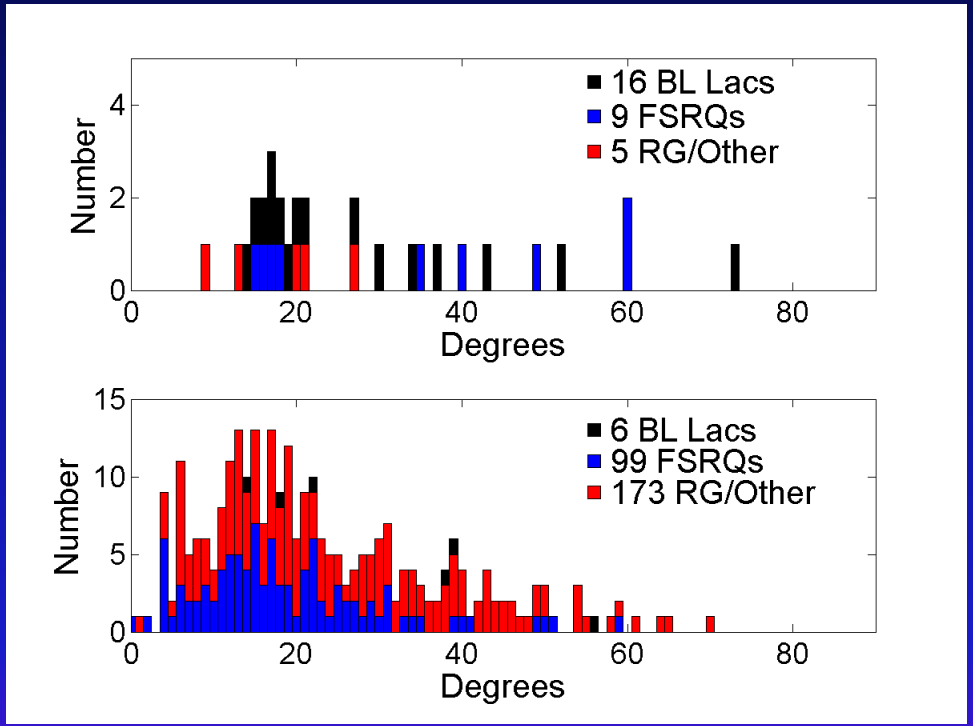


Stacked histograms
Top: LAT
Bottom: non-LAT

- LAT core T_Bs tend to be higher than non-LAT. Except BL Lacs.
- Kolmogorov-Smirnov (K-S) tests indicate that the FSRQs are very different, but BL Lacs are similar.

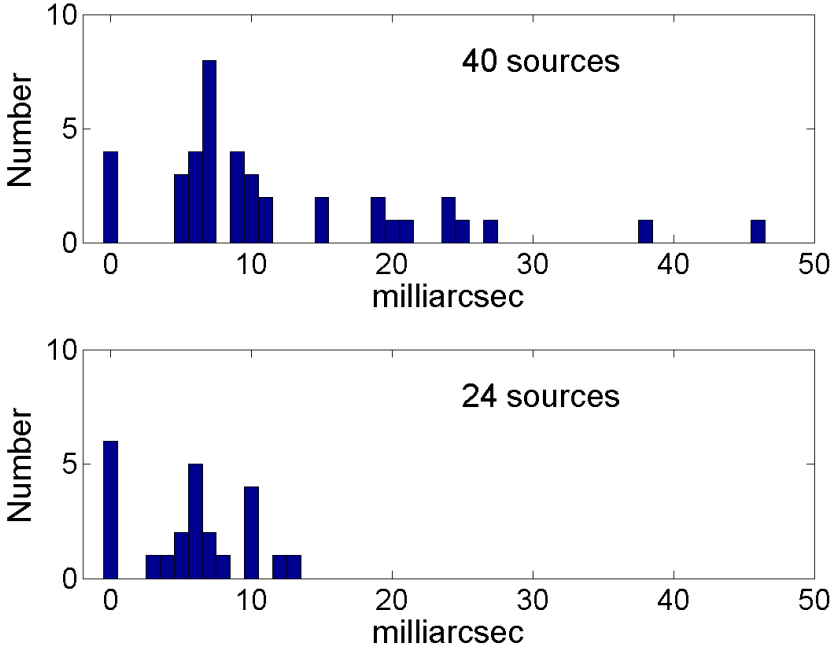
Jet Opening Angle

- Only had opening angle measurements for 30 LAT sources.
- There is evidence that LAT sources have larger opening angles, especially FSRQs.



Stacked histograms
Top: LAT
Bottom: non-LAT

Jet Characteristics



BL Lac Jet Lengths
Top: LAT
Bottom: non-LAT

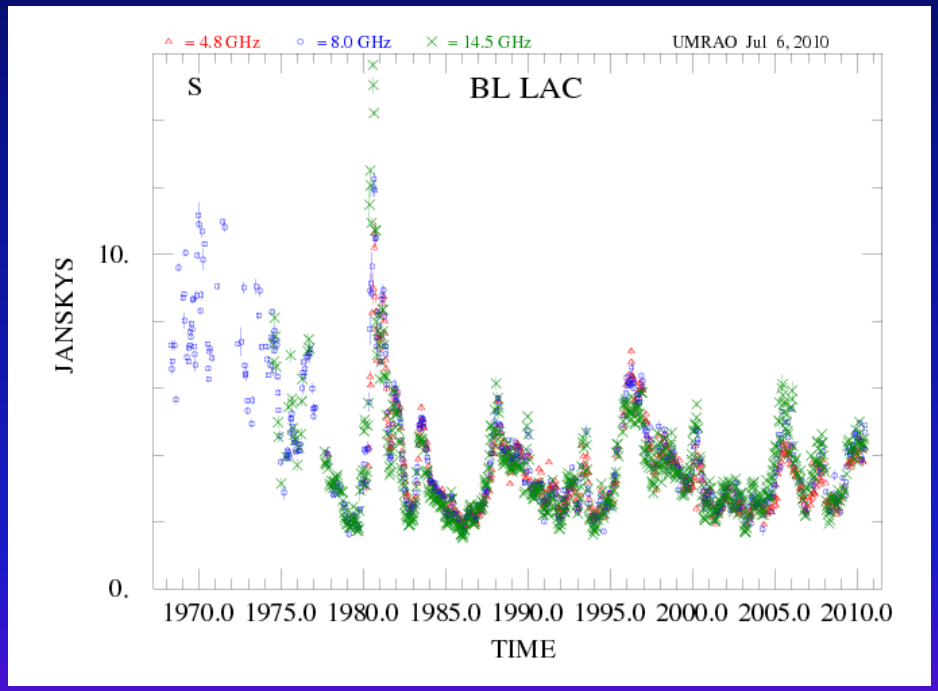
- Jet bending (ΔPA) and jet brightness temperatures are very similar for LAT and non-LAT sources.
- Jet lengths are similar for FSRQs and RG/other.
- LAT BL Lacs have longer jets than non-LAT BL Lacs (K-S: 2.1%).

BL Lacs

- Nearly 2/3 of the BL Lacs in VIPS are detected by Fermi.
- The only difference between the LAT and non-LAT populations is the LAT BL Lacs have longer jets.
- Longer jets indicate either higher material velocity or larger orientation angle.
- But a larger orientation angle would result in a smaller Doppler factor, and therefore less γ-ray flux.
- So, the LAT BL Lacs probably have higher material velocities in their jets.

BL Lacs: Variability

- BL Lacs are known to be highly variable.
- It is possible that the γ-ray quiet BL Lacs are in a low γ-ray state.
- The γ-ray variability may be related to variability in the jet material velocity.



BL Lac light curve
Hugh & Margo Aller
UMRAO

FSRQs

- LAT FSRQs appear to be very different from the non-LAT FSRQs.
- Only about 9% (50/529) of the VIPS FSRQs are γ-ray loud.
- γ-ray flux correlates with radio flux density for the FSRQs.
- The core brightness temperatures are higher for LAT FSRQs and they appear to have larger opening angles.

FSRQs

- It seems that the LAT FSRQs are extreme sources.
- The γ-ray loud FSRQs can be explained with Doppler boosting, but they require a substantially higher Doppler factor than the γ-ray loud BL Lacs.
- Lister et al. (2009) reported that the median jet speeds for LAT FSRQs were more than a factor of 2 faster than for the LAT BL Lacs.

Constraints on Gamma-ray Emitting Region

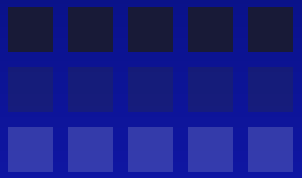
- Notice that all of the differences between LAT and non-LAT objects are related to the cores.
- This indicates that the γ-rays originate in or near the central engine.
- Using the nearest 7 objects, we get an upper limit on the size of the γ-ray emitting region of 0.9 pc.

$H_0 = 71$ km s^{-1} Mpc^{-1}, ΛCDM cosmology

Conclusions

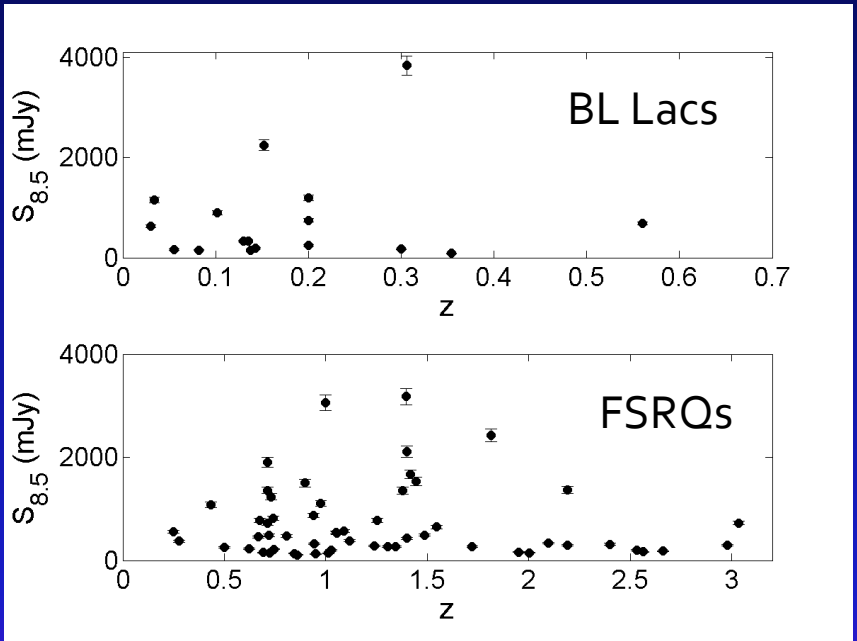
- BL Lacs are probably all producing gamma-rays, but we don't detect some because of low Doppler factors and/or variability.
- Gamma-ray loud FSRQs are extreme sources with high radio flux densities and high brightness temps.
- Core polarization is a signature of gamma-ray emission.
- The gamma-rays are coming from the base of the jets.

Backup slides



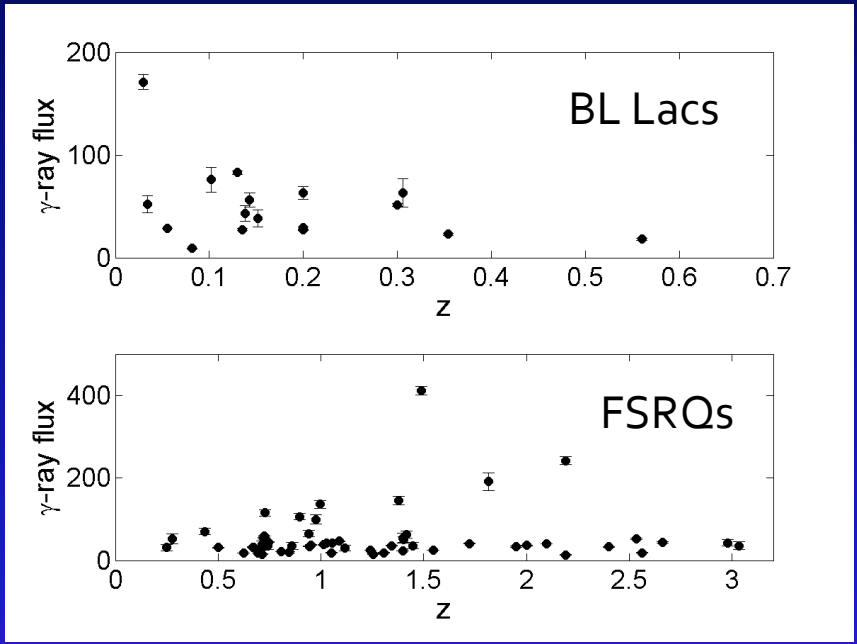
No Redshift Correlations

Radio Flux Density



BL Lacs: rho = 0.07, P=78%
FSRQs: rho = -0.04, P=74%

Gamma-ray Flux



BL Lacs: rho = -0.3, P=21%
FSRQs: rho = 0.1, P=45%
γ-ray flux is in units of 10^{-9} ph cm^{-2} s^{-1}

Correlation in Other Studies

- The MOJAVE sample is somewhat smaller than the VIPS sample and has a higher cut-off. AT20G is larger than VIPS, but is dominated by bright sources.
- Our large sample, with its lower radio flux density cut-off, shows that the correlation does NOT hold for dimmer sources.
- Why do others see a correlation?
  - The other studies are dominated by bright ($S_\nu > 500$ mJy) FSRQs.
  - We can reproduce the correlation seen by others if we use the brightest 36 objects in our sample.

Radio Galaxies/Others

- The major difference between the LAT and non-LAT RGs is that 67% of the LAT RGs have polarization in their cores, compared to only about 20% for the non-LAT RGs/Others.
- Note: we used the optical classification system from CGRaBS (Healey et al. 2008). There is controversy about the classification of several of the objects we call RGs.

Compact Symmetric Objects

- Stawarz et al. (2008) predicted there should be many CSOs among LAT detections due to inverse Compton scattering of ultrarelativistic electrons in their lobes.
- However, there are no compact symmetric object candidates among the LAT sources in our sample or any other survey, to date.