Why Haven't Many of the Brightest Radio Loud Blazars Been Detected by Fermi?

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Lister et al. 2015, ApJ Let., 810, 1

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(The answer: ☺)

- It's both a selection effect of the Fermi-LAT instrument, and a result of Doppler boosting of AGN jet emission.
- The sensitivity and passband limits of the LAT make it far less likely to detect blazars with lower boosting factors and rest frame synchrotron SED peaks below $10^{13.4}$ Hz.

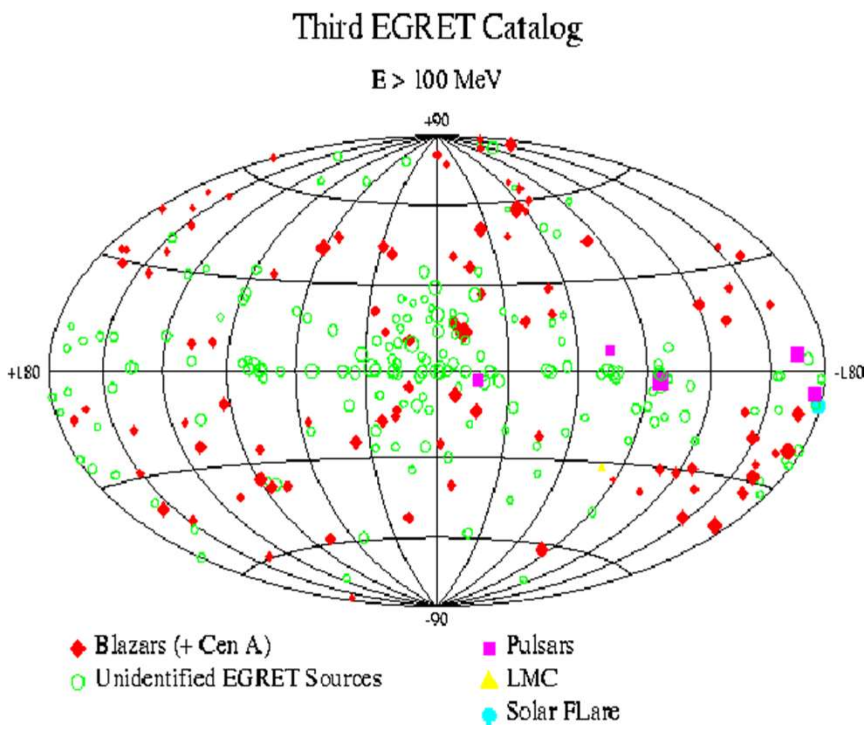
The Problem

- **1990s:** *EGRET* instrument on the CGRO detected ~100 AGN

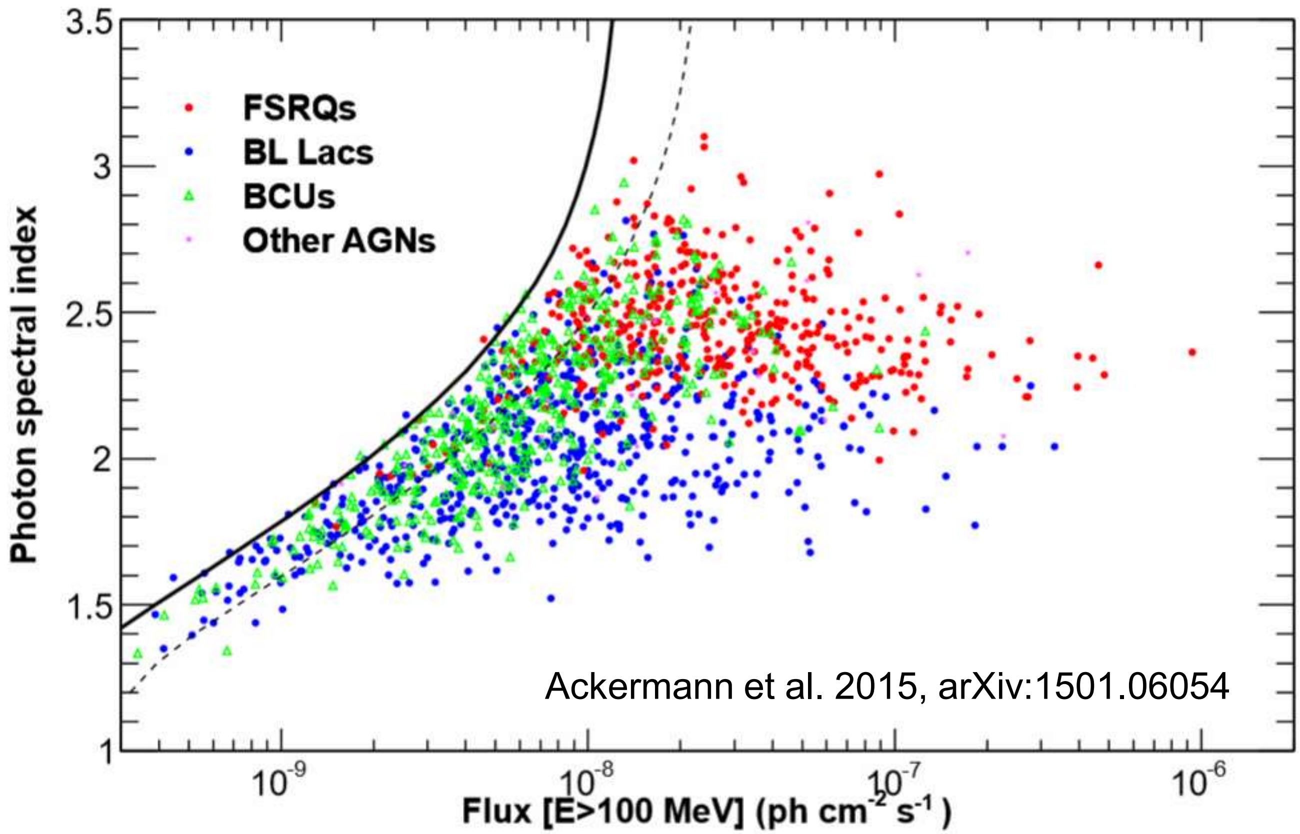
  → nearly all were blazars

- Indicated that AGN gamma-ray flux is highly sensitive to relativistic Doppler boosting.

- Unclear why many highly variable, superluminal blazars were never detected (e.g., 0605-085, 1308+326, 1749+096)
  - flaring duty cycle?
  - insufficient instrument pointings?
  - problems with association IDs?
  - shape of their SEDs?



3rd Fermi LAT AGN Catalog (3LAC)



- 1591 AGNs detected above 100 MeV using 4 years of LAT data.
- Harder (higher spectral peaked) AGNs are detected down to much lower photon fluxes.

MOJAVE 1.5 Jy Sample

- AGN radio flux densities can vary by factors of up to ~10 over decadal timescales (OVRO and U. Michigan monitoring programs)

- We compiled a list of all 181 (non-lensed) AGN above δ = -30° known to have exceeded 1.5 Jy in 15 GHz VLBA flux density between 1994.0 and 2010.0

- Like the Fermi 3LAC sample, the selection is based purely on *multi-epoch, small (pc)-scale jet flux*, with negligible obscuration effects.

- **Despite 4 years of LAT observations, 23% of the 163 high-galactic latitude >1.5 Jy AGN still have no gamma-ray associations.**

Observational Data

1. **Synchrotron peak frequencies:**
   - large dispersion of published peak values for the same sources
   - spectral energy distribution (SED) builder tool at ASDC

2. **Doppler boosting indicators:**

   a) fastest measured jet speed from MOJAVE program (Lister et al. 2013),

   b) OVRO 15 GHz modulation (variability) index (Richards et al. 2014),

Observational Data (continued)

3. Duty cycle (flux variability):

- compiled maximum 15 GHz flux densities during:
  - a) start of 1.5 Jy selection window and Fermi launch (1994-2008)
  - b) 3LAC observational window (2008-2012)
- ratio of these two maxima = radio activity indicator

4. Flux density and luminosity

- compiled median flux densities during 3LAC window
- redshifts available for 98% of the sample

Analysis

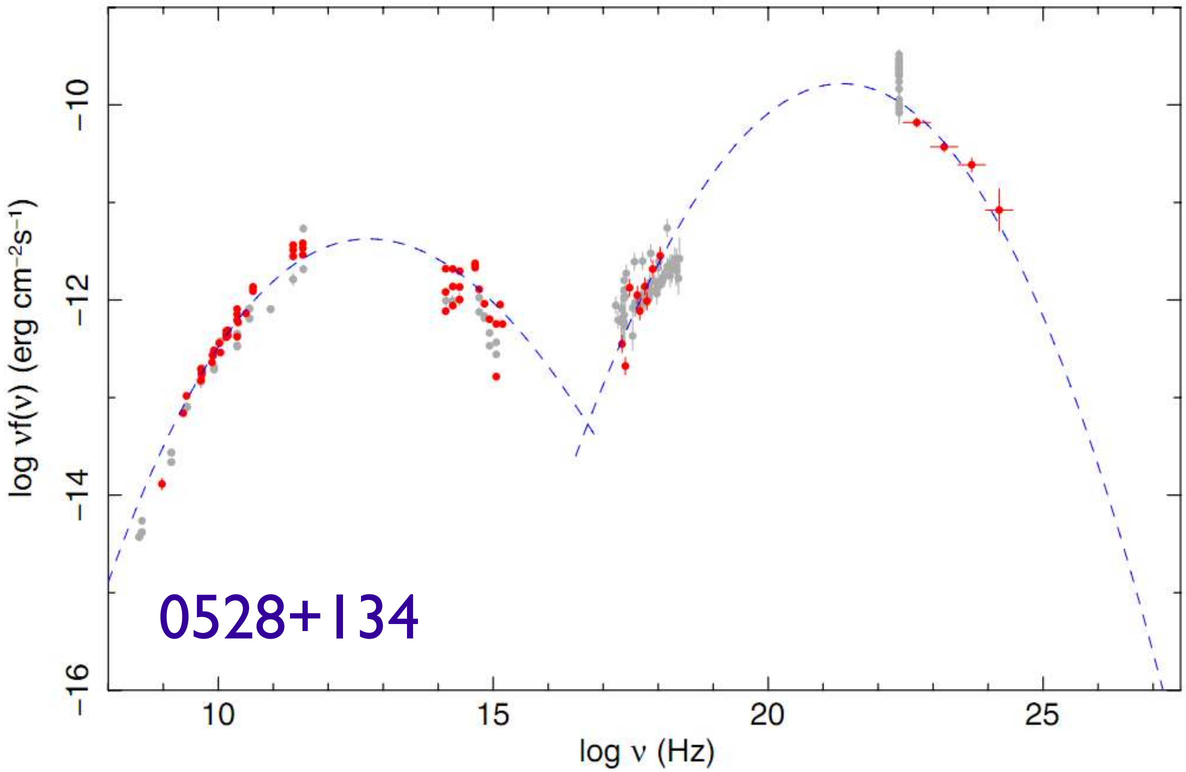
- We compared general properties of LAT-detected vs. non-LAT-detected AGN in the MOJAVE 1.5 Jy sample using non-parametric statistical tests.

Property	Kolmogorov–Smirnov	Wilcoxon Rank Sum
Synchrotron peak location (observed)	1×10^{-4}	3×10^{-5}
Synchrotron peak location (rest frame)	1×10^{-4}	1×10^{-5}
Maximum observed jet speed	2×10^{-6}	3×10^{-5}
15 GHz modulation index	5×10^{-4}	9×10^{-5}
Redshift	0.50	0.45
Radio activity index[a]	0.10	0.14
Median VLBA radio flux density[a]	0.86	0.50
Maximum VLBA radio flux density[a]	0.04	0.05
Median VLBA radio luminosity[a]	0.86	0.80
Maximum VLBA radio luminosity[a]	0.76	0.73

Probability of obtaining the observed distributions in the two sub-samples under the null hypothesis that they are from the same parent distribution.

The Role of the SED

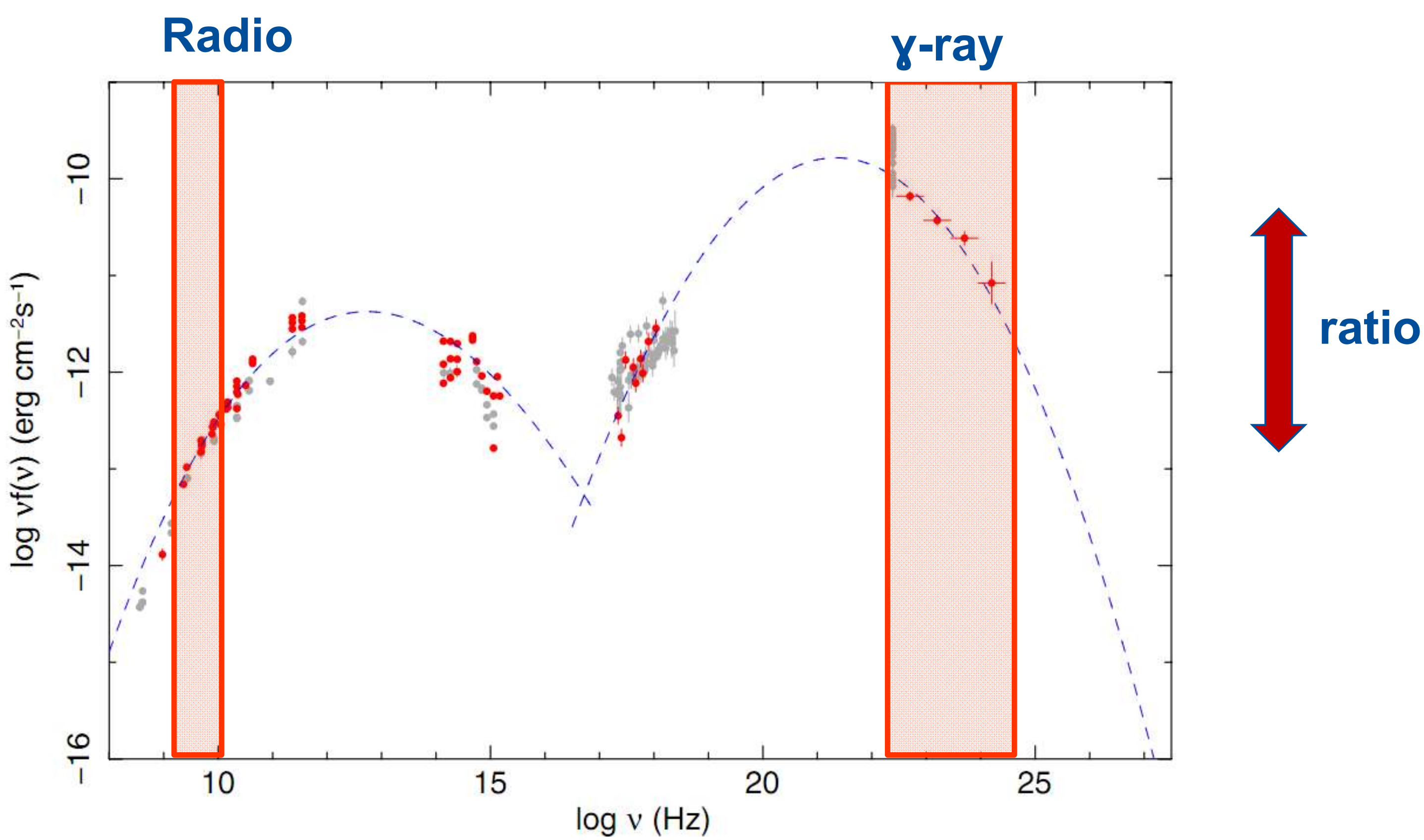
- Let's assume the synchrotron and inverse-Compton SED peak locations in blazars generally track each other.



Abdo et al. 2010, ApJ 716, 30

Fixed passbands and ɣ-ray/radio flux ratio

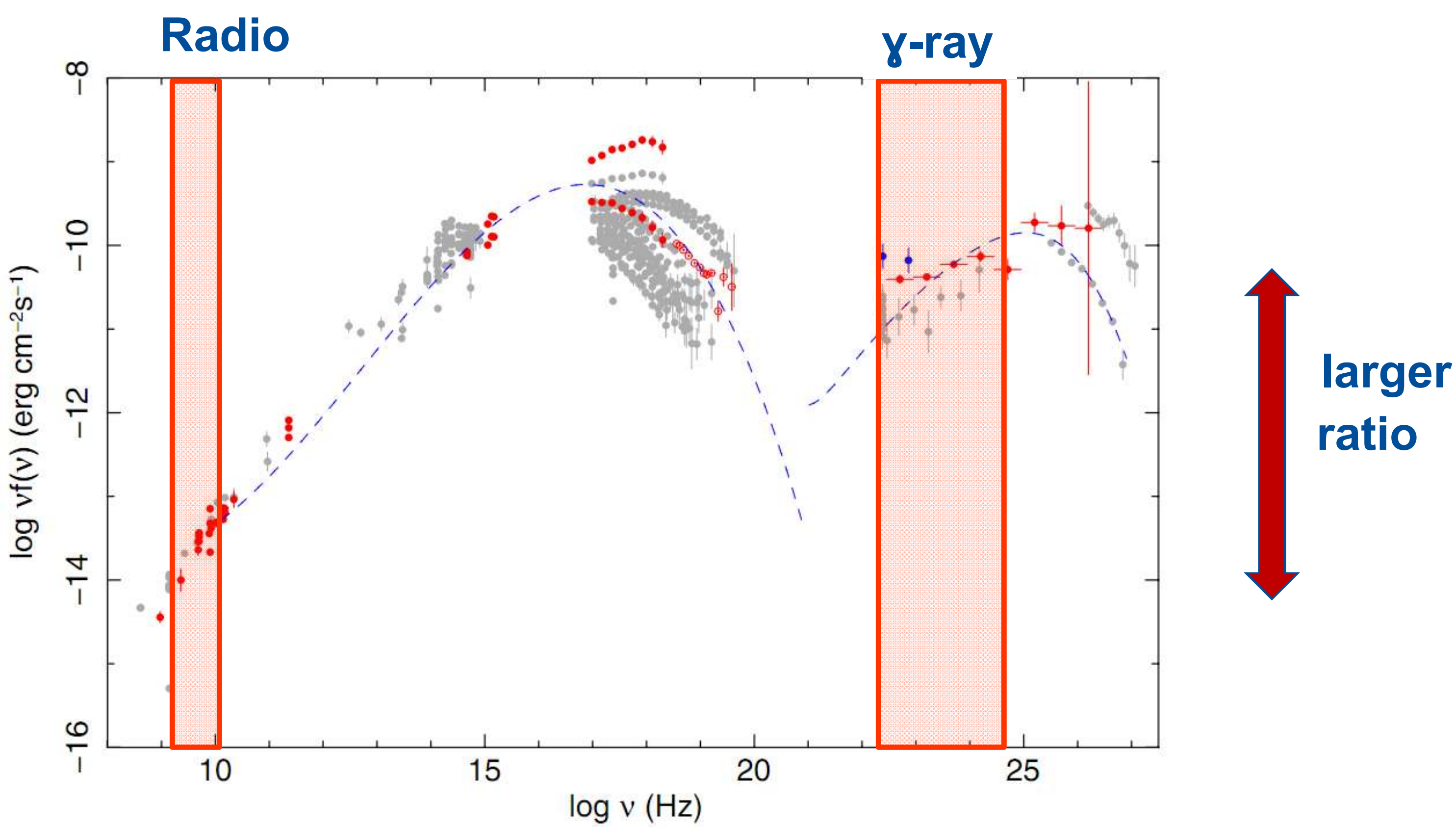
- 0528+134: Low-spectral peaked quasar at z=2
- Moderate apparent ɣ-ray to radio luminosity ratio



Abdo et al. 2010, ApJ 716, 30

Fixed passbands and ɣ-ray/radio flux ratio

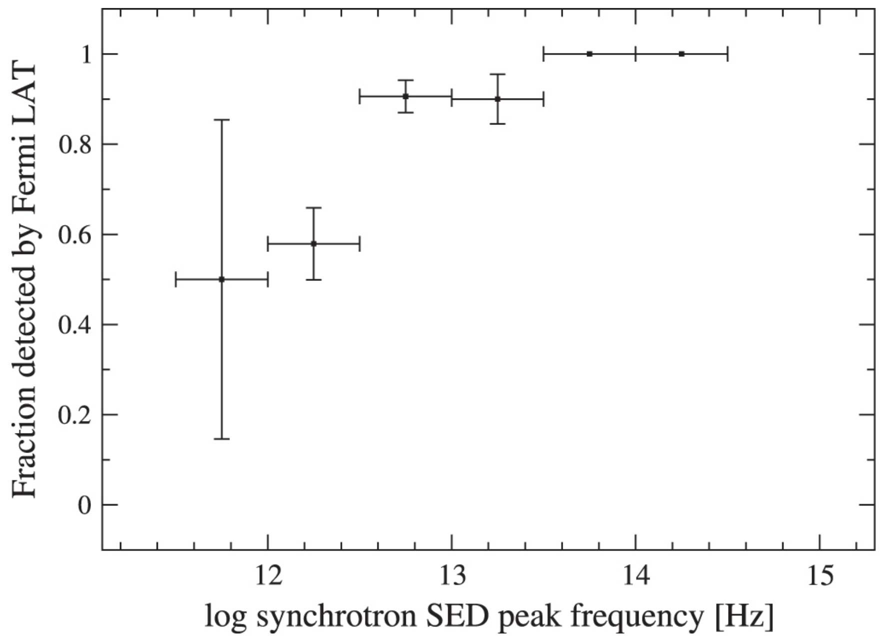
- Mk 421: High-spectral peaked BL Lac at z = 0.033
- Larger apparent ɣ-ray to radio luminosity ratio

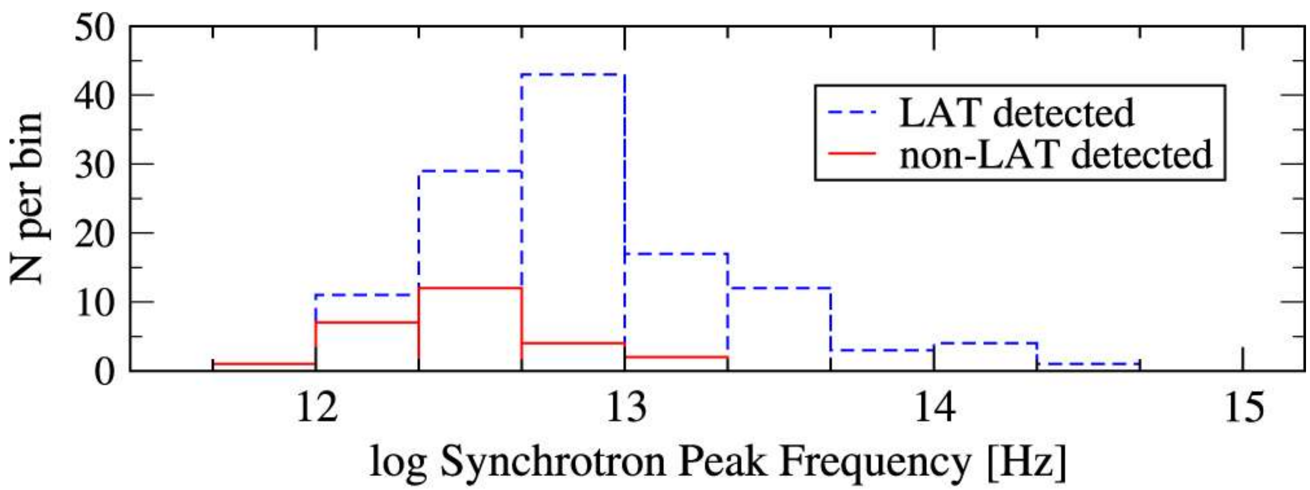


Abdo et al. 2010, ApJ 716, 30

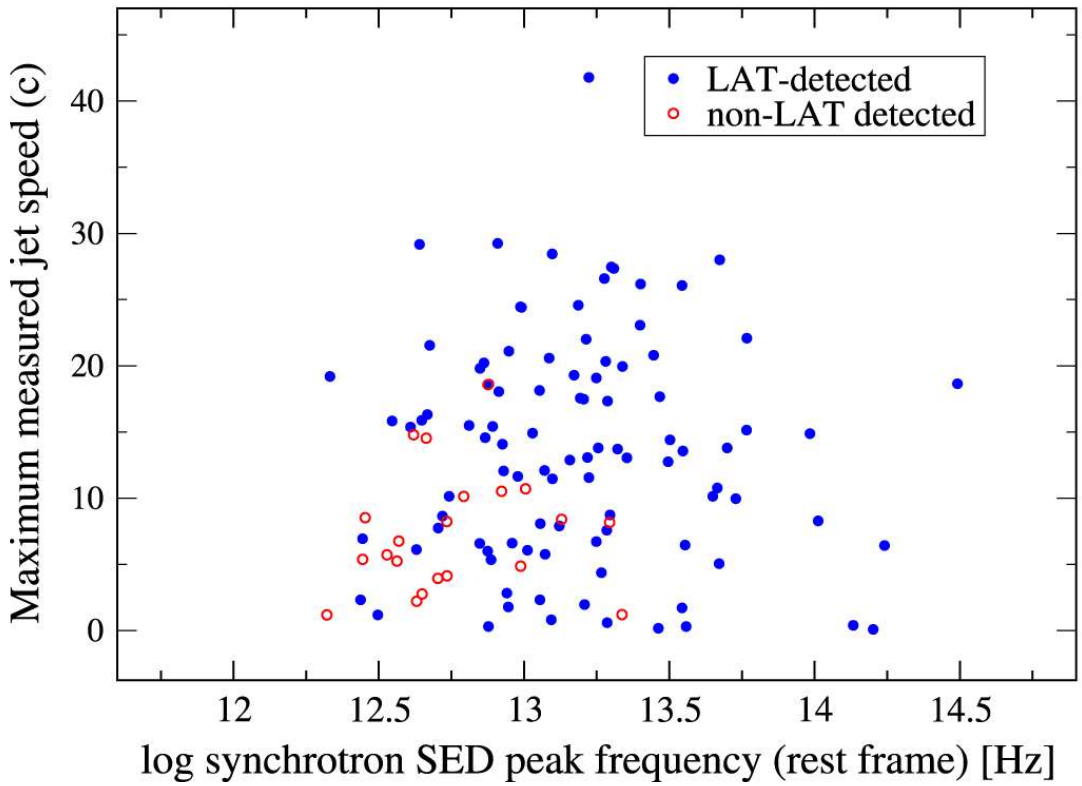
The Role of the SED

- All other things equal, in a radio flux-limited blazar sample, we would expect LAT detections to favor higher synchrotron peaked AGNs





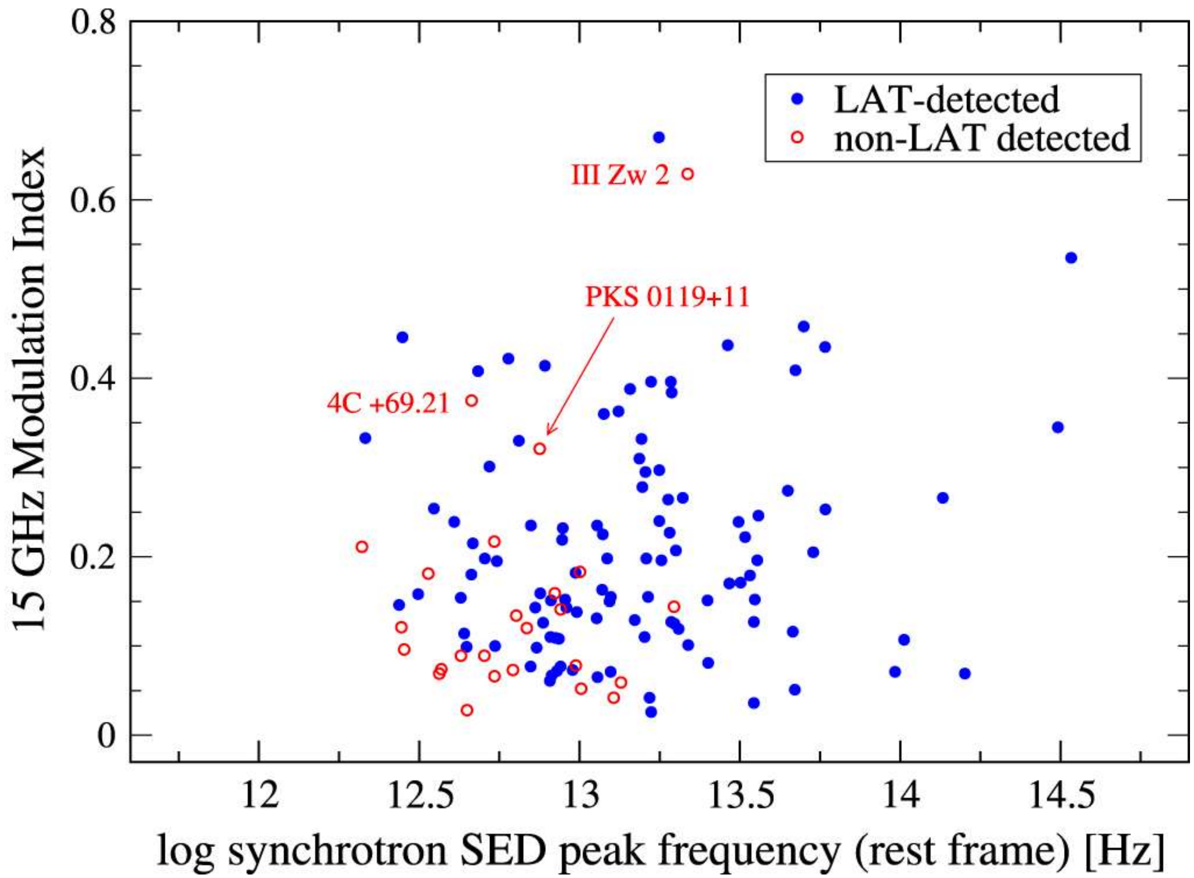
The Role of Doppler Boosting



All of the fastest jets in the 1.5 Jy sample have LAT detections.

- External IC model predicts higher effective flux boosting in gamma-rays than radio, due to blueshifting of external seed photons in jet frame.
- Standard $(1+z)^{\alpha}$ k-correction gives added boost since AGN spectra are steeper in gamma-rays than radio.

The Role of Doppler Boosting (continued)



- With only a few exceptions, all of the most highly radio variable 1.5 Jy AGN have LAT detections.

Summary

- Using a complete jet flux-limited radio-AGN sample (MOJAVE 1.5 Jy), we investigated why after 4 years of observations, a large fraction of powerful beamed AGN jets still have not been detected by Fermi.
- The sensitivity and passband limits of the Fermi LAT make it far less likely to detect AGN with lower Doppler boosting factors and rest frame synchrotron SED peaks below $10^{13.4}$ Hz.
- Future instruments covering the MeV range stand to detect large numbers of AGN and are essential for fully understanding the SEDs and demographics of the blazar population.

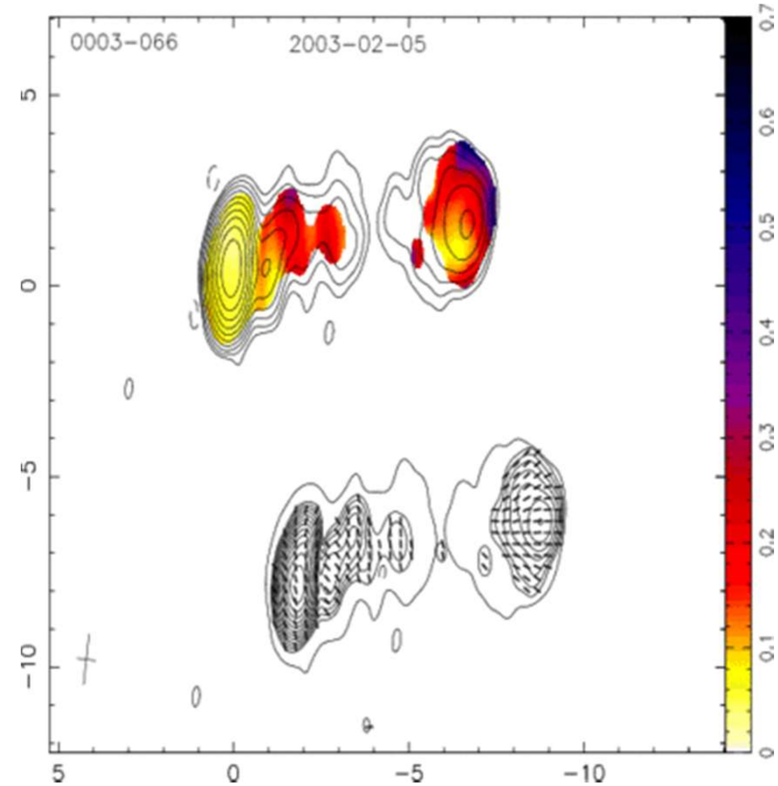
Lister et al. 2015, ApJ Let., 810, 1

www.astro.purdue.edu/MOJAVE

Backup slides

MOJAVE VLBA Program

- Regular observations of radio-bright AGN
  - VLBA Key Science project
- 24 hour observing session every month
  - cadences tailored to individual jets
- Milliarcsec-resolution images at 15 GHz
  - continuous time baselines on many sources back to 1994
  - full polarization since 2002

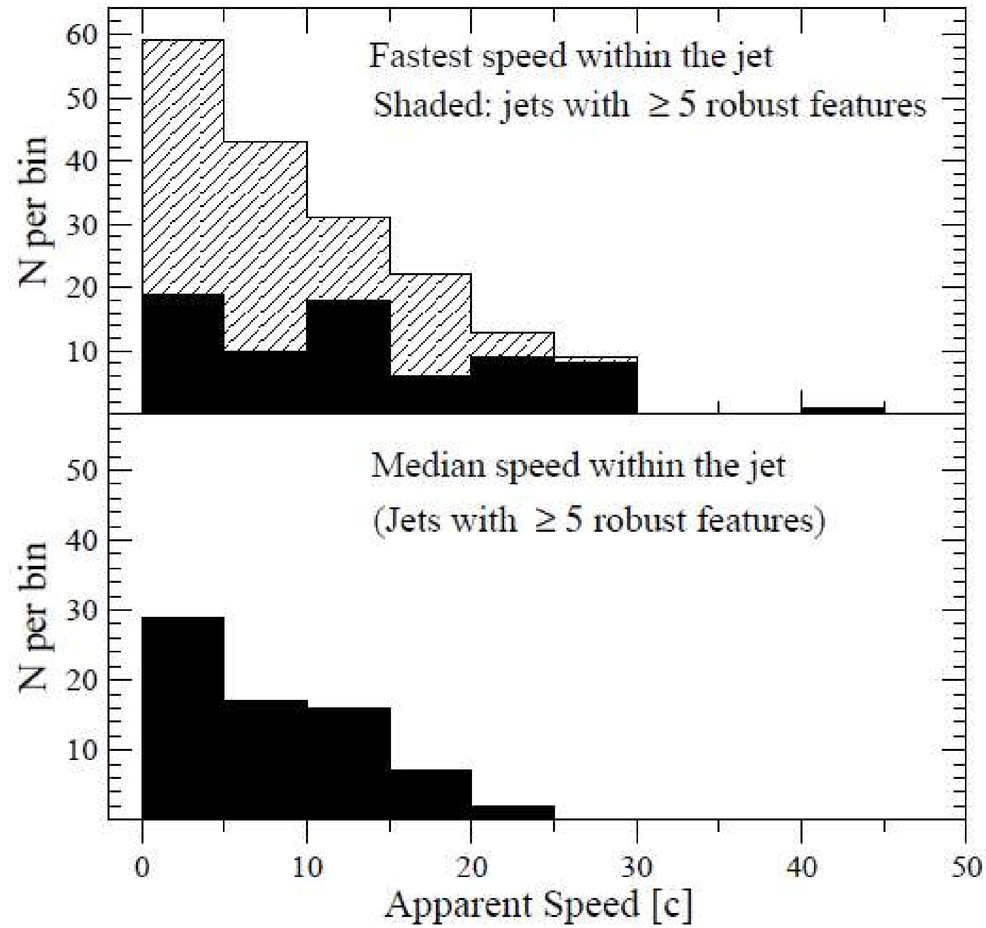


Blazar 0003-066 at 15 GHz

Colors: fractional linear polarization

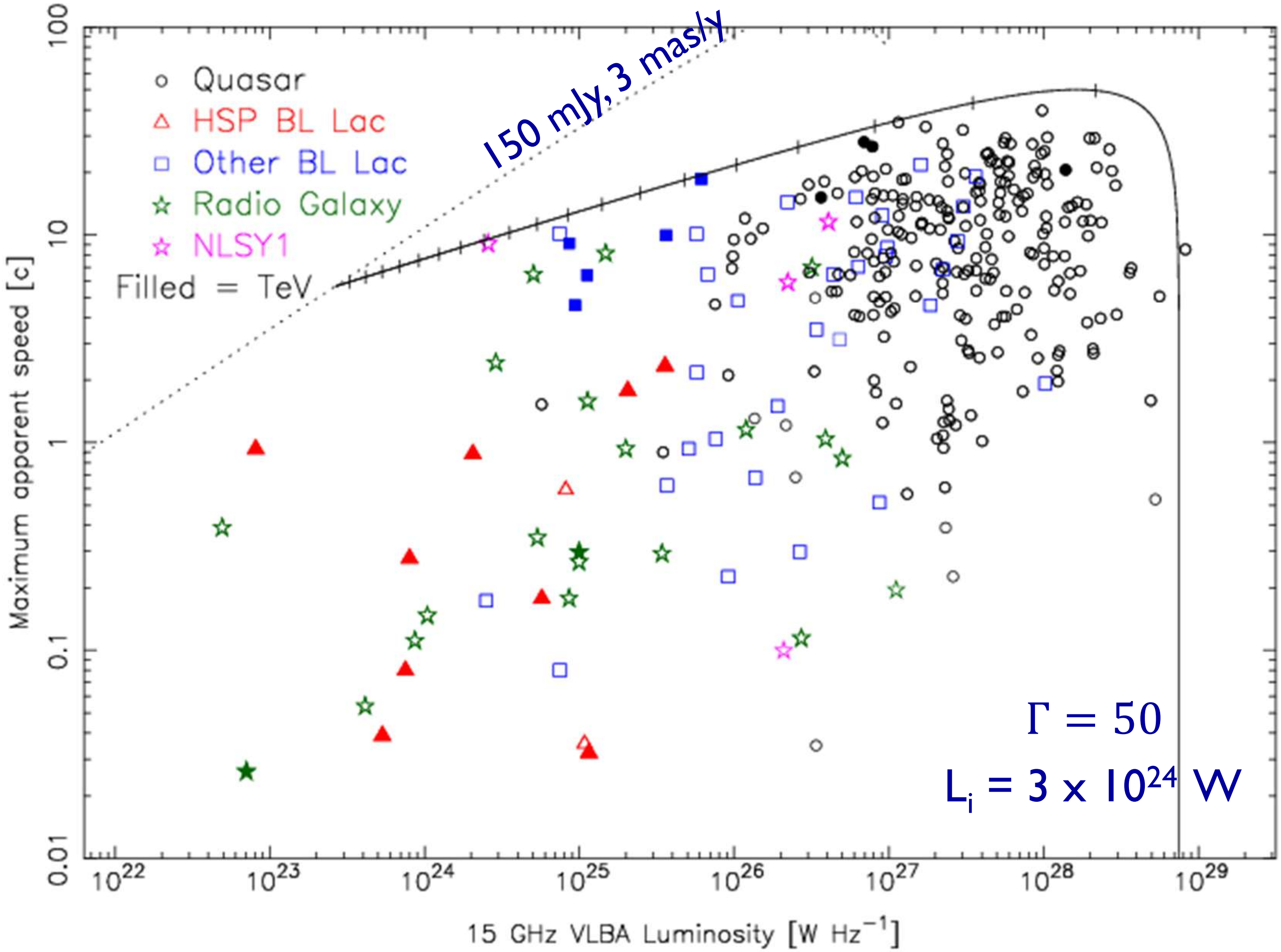
Overall Jet Speed Distribution

- Peaked at low values
  - only 2 jets with $\beta_{app} > 30$
  - high Γ jets are very rare in blazar parent population
- Lorentz factors of the most luminous/powerful jets range up to ~50
- The typical AGN jet is weak and has a Lorentz factor of only ~ a few



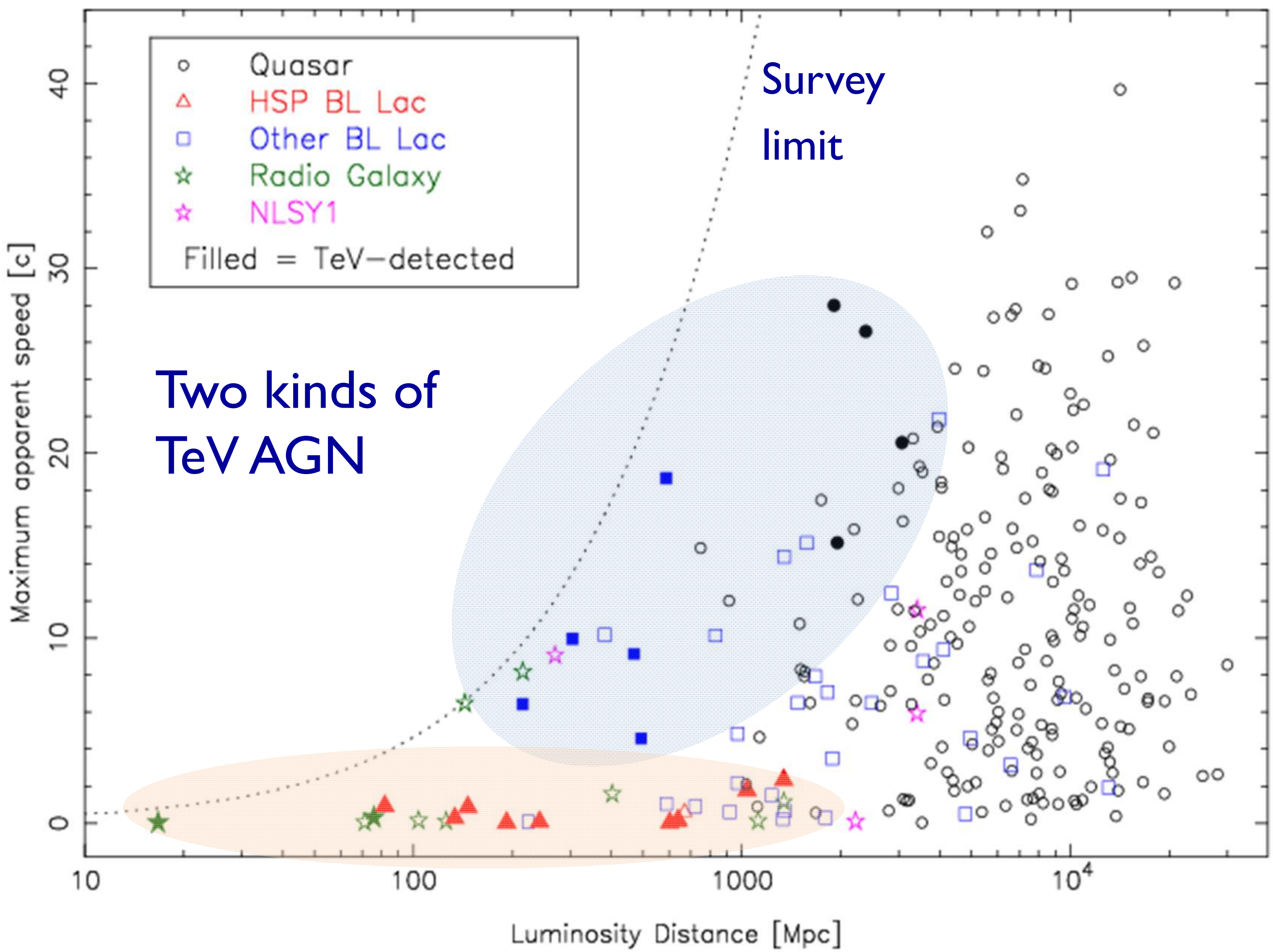
Lister et al. 2013, AJ 146, 120

Jet Speed vs. 15 GHz Luminosity

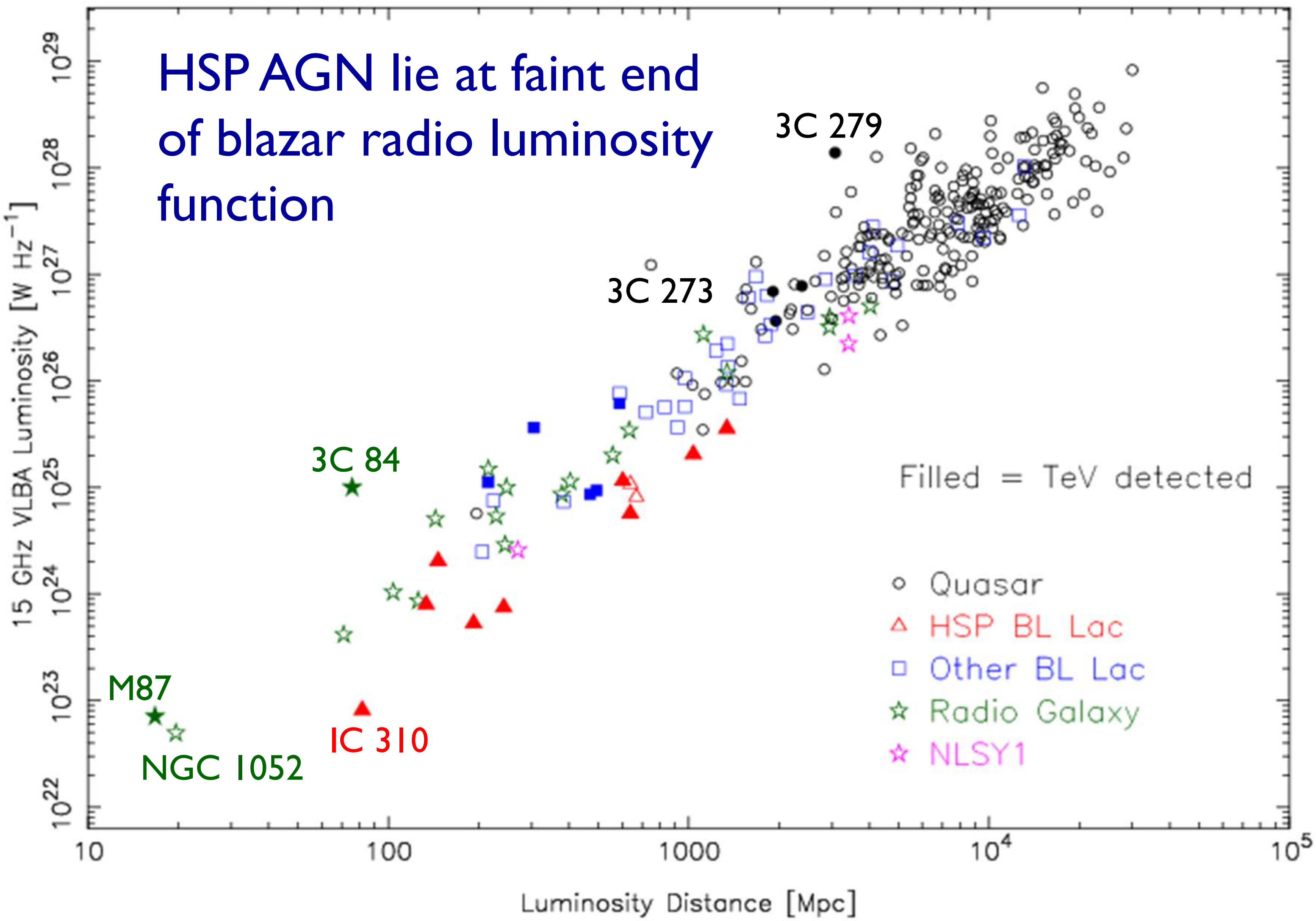


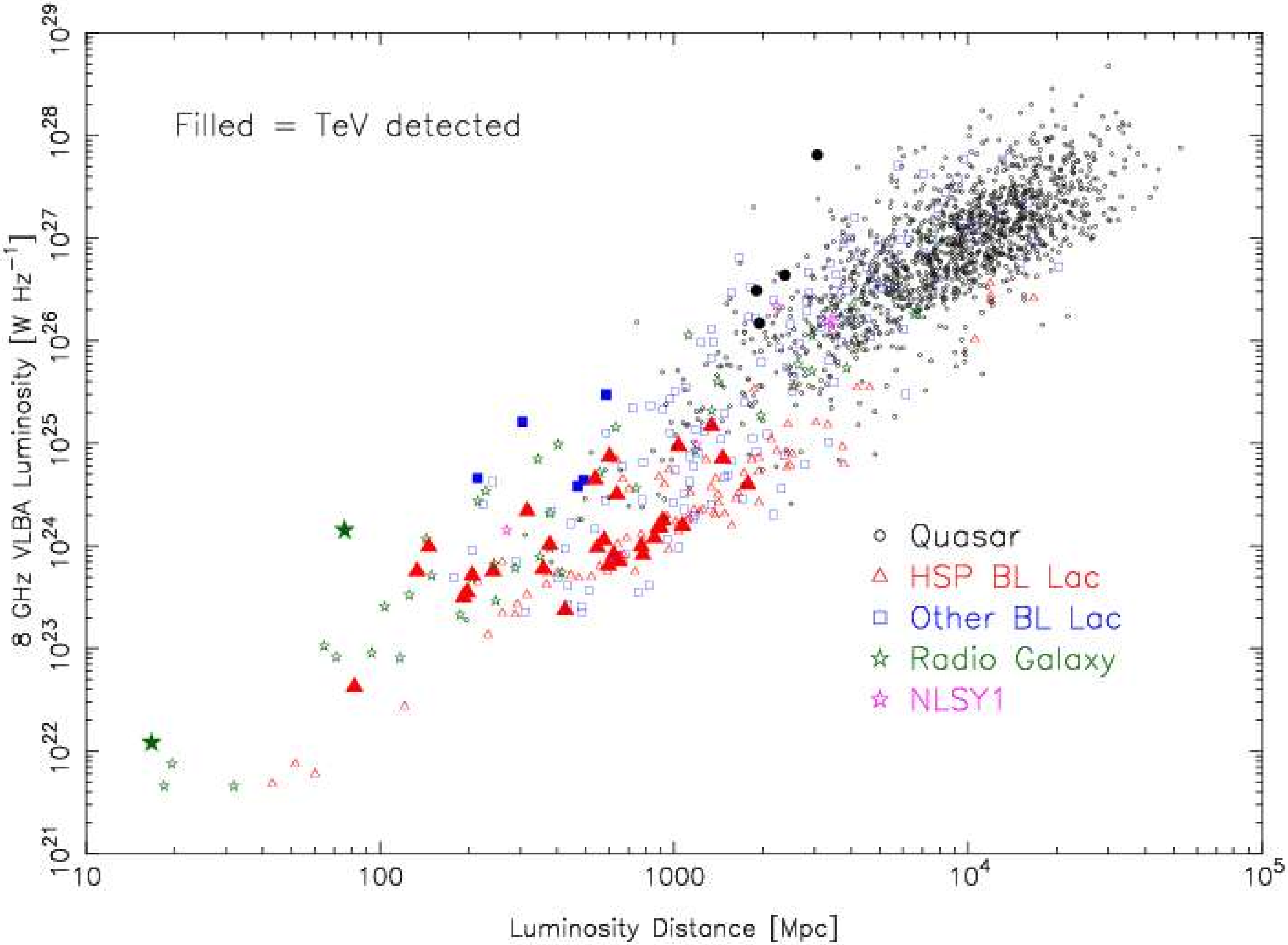
Only the most luminous jets can attain high Lorentz factors

Jet Speed vs. Cosmic Distance

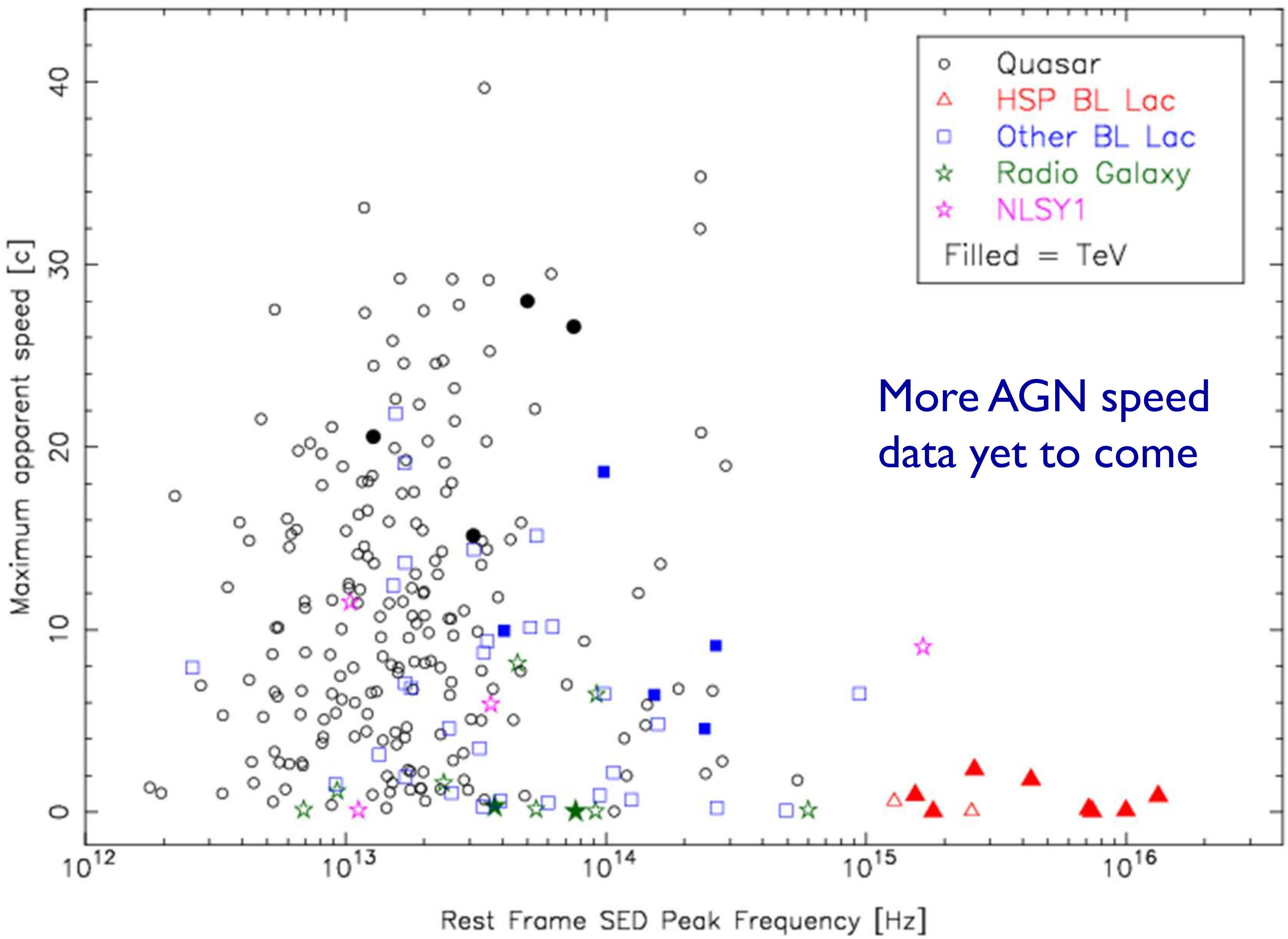


Radio Jet Luminosity vs. Cosmic Distance




Filled = TeV detected
8 GHz VLBA Luminosity [W Hz^{-1}]
Luminosity Distance [Mpc]
Quasar
HSP BL Lac
Other BL Lac
Radio Galaxy
NLSY1
10
100
1000
10^{4}
10^{5}
10^{21}
10^{22}
10^{23}
10^{24}
10^{25}
10^{26}
10^{27}
10^{28}
10^{29}

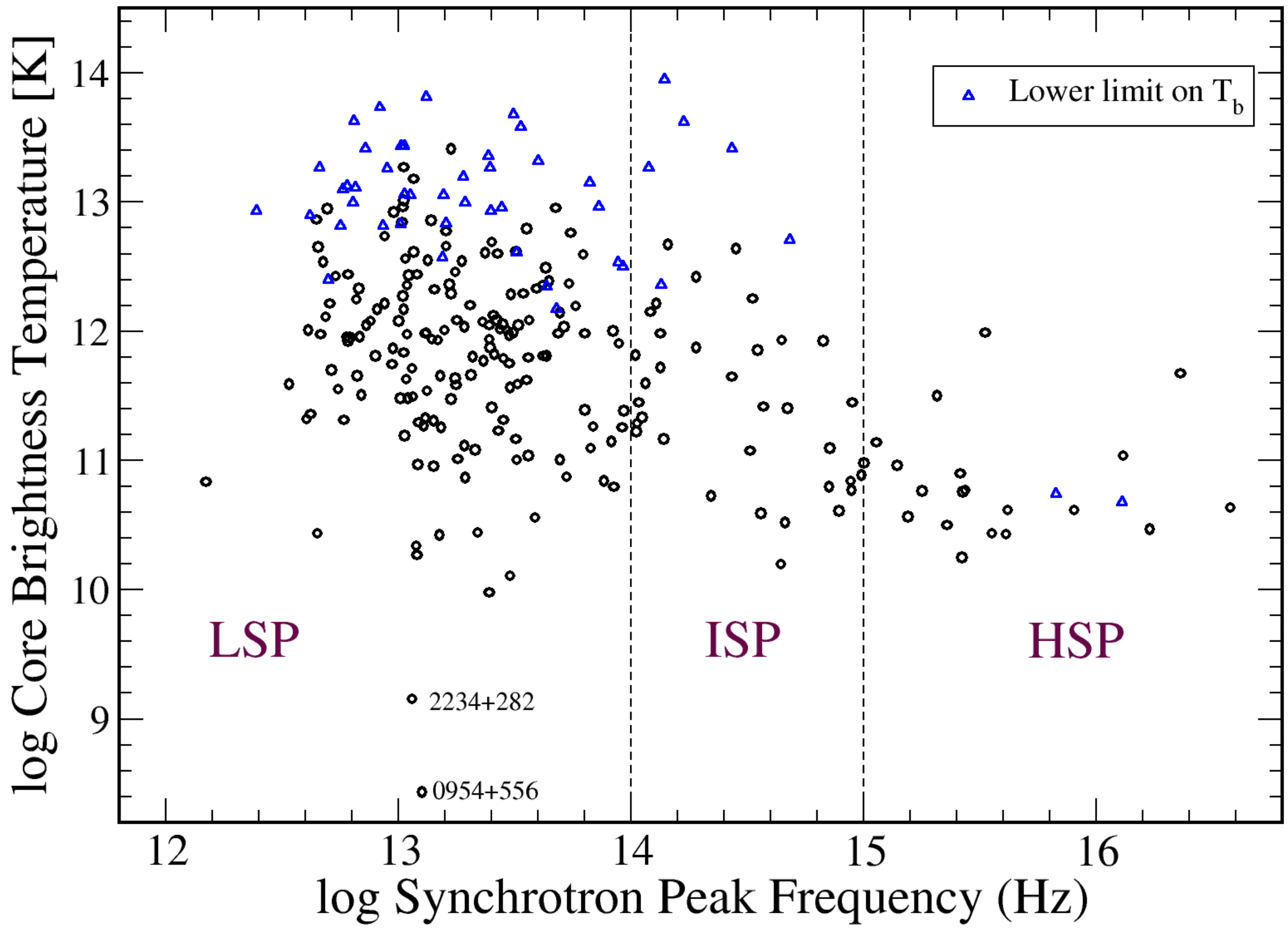
Jet Speed vs. Synchrotron Peak Frequency



More AGN speed data yet to come

Relativistic Beaming Levels

$T_{B,obs} \sim \delta \, T_{B,int}$



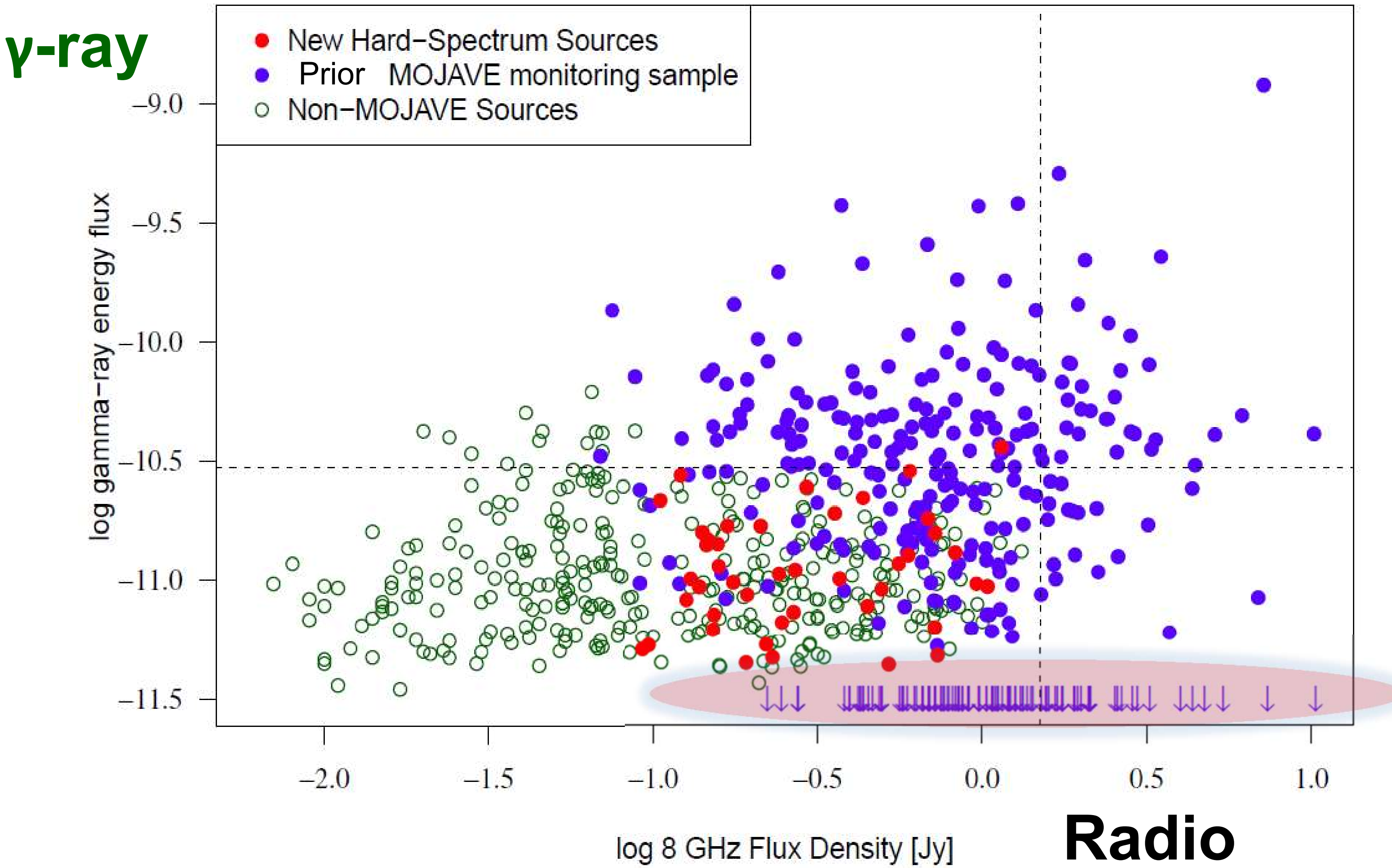
- Lower VLBI brightness temp. and variability of HSP radio cores are indicative of low radio relativistic beaming factors

Current BL Lac Paradigm

- Lower jet power implies low accretion rate onto black hole:
  → inflow radiates inefficiently, thus no optically thick accretion disk or broad line region

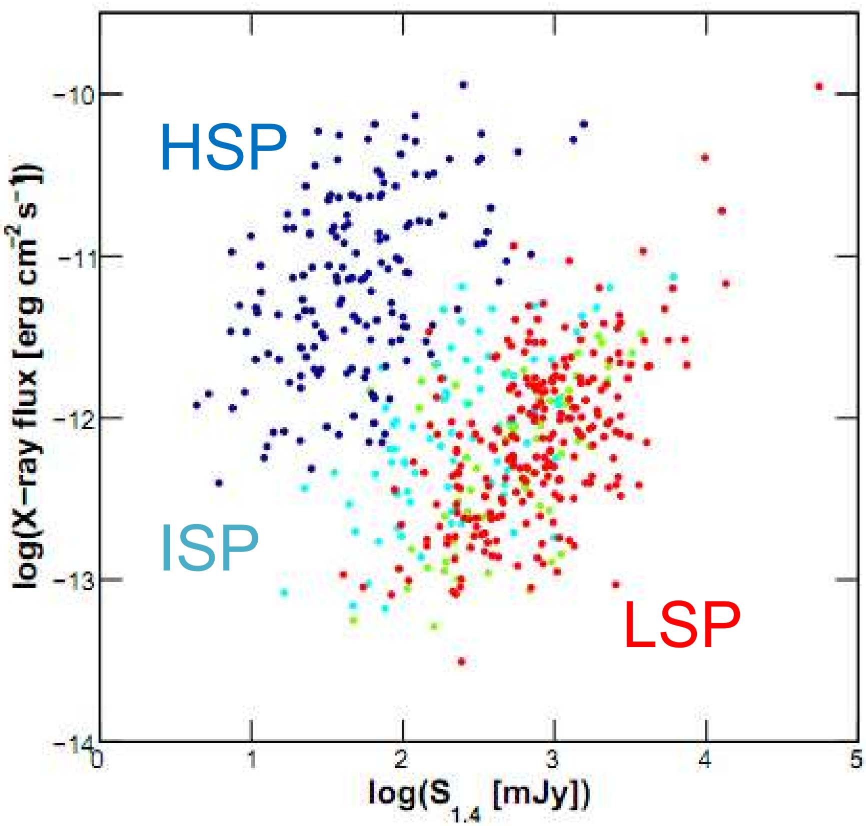
- No broad line photons are available for external Compton scattering
  → less Compton cooling of synchrotron electrons
  → synchrotron can peak up to optical/UV regime

Radio Blazars in the Fermi Era



Investigating *Fermi* blazar jets

X-ray vs. radio flux



Fermi LAT Collab, 2012, ApJ 743, 171

- ***Fermi* LAT is an excellent AGN survey instrument:**
  - has longterm near-continuous, broadband coverage, sees jet flux only, with no contamination from host galaxy
- Quasars (red points) have low-spectral peaked SEDs
- IC scattering of broad line region photons quenches high energy electron population in the jet
- Highest spectral peaked (HSP) jets are of the less powerful BL Lac class (no broad line region)