Fermi Gamma-ray Space Telescope

The connection between radio and gamma-ray emission in AGN

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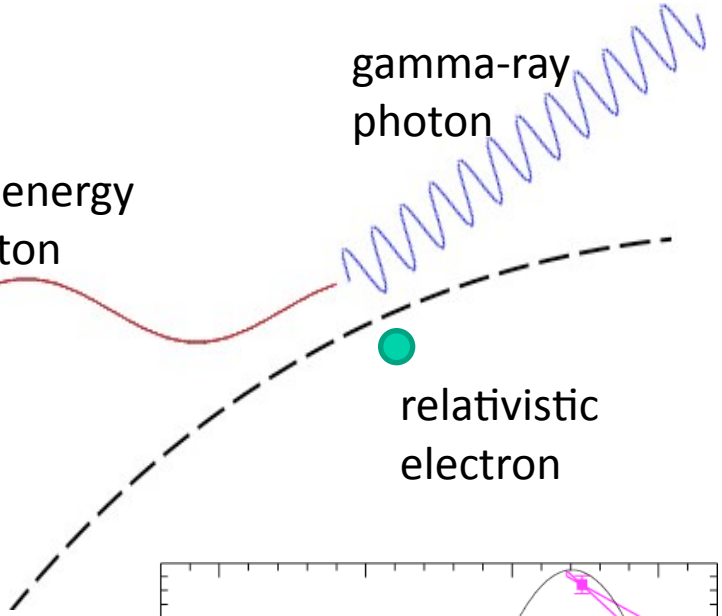
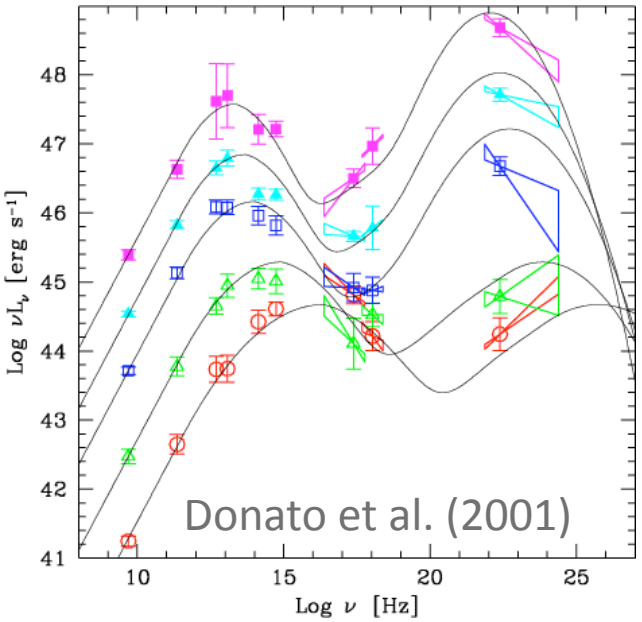
on behalf of the Fermi-LAT collaboration

Background

- **synchrotron radio emission originates from relativistic electrons that can upscatter photons to high energy**
  - **some connection between radio and gamma-ray properties is expected!**
  - **observationally, all EGRET AGNs are radio loud, differently from most X-ray QSOs**
- **the blazar sequence was originally devised on the basis of the radio luminosity**
- **evidence or not of flux-flux, Lum-Lum correlations is a debated issue**
  - **Mücke et al. (1997), Taylor et al. (2007), Bloom (2008), etc.**
  - **bias, variability, number of sources, etc.**



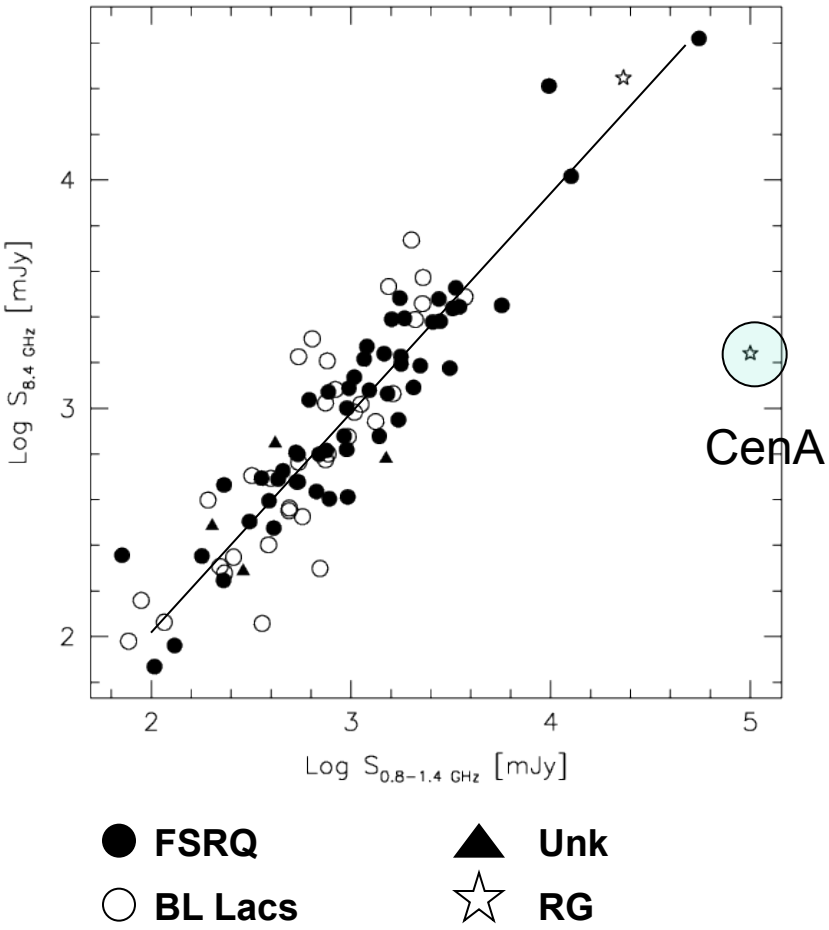


LAT Bright AGN Sample (LBAS, Abdo et al. 2009)

- 125 non-pulsar sources at |b|>10° with TS>100
  - 106 high-confidence (P>90%) associations with AGNs: (LBAS)
  - 10 lower-conf. associations, 9 unass. (3EG: 96/181 at |b|>10°)
- Radio properties typical of compact self-absorbed components
  - relatively bright: 98/106 (92%) have $S_{8.4}$>100 mJy
  - flat spectral index: α=0.02+/-0.27
- High-confidence associations:
  - FSRQs: 58
  - BLLacs: 42 (including 7 HBLs)
  - Uncertain class: 4
  - Radiogalaxies: Cen A, NGC1275
- LBAS sources are associated to CRATES/BZ Cat sources:
  - CRATES: Healey et al. (2007, 8.4 GHz VLA data)
  - BZCAT: Massaro et al. (2009, multifrequency catalog)

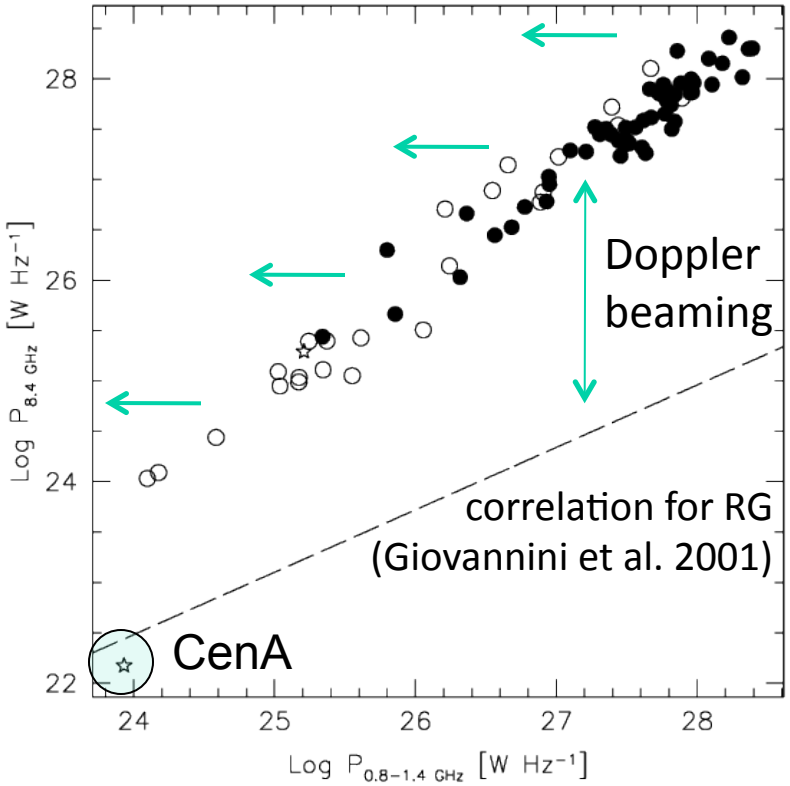
Low vs high radio frequency: flux-flux

- not subject to distance bias
  - Low frequency from NVSS (1.4 GHz) or SUMSS (0.8 GHz)
  - High frequency typically from CRATES (8.4 GHz, or NED)
- another representation of the spectral index flatness
- little to none extended radio emission
  - except Cen A!



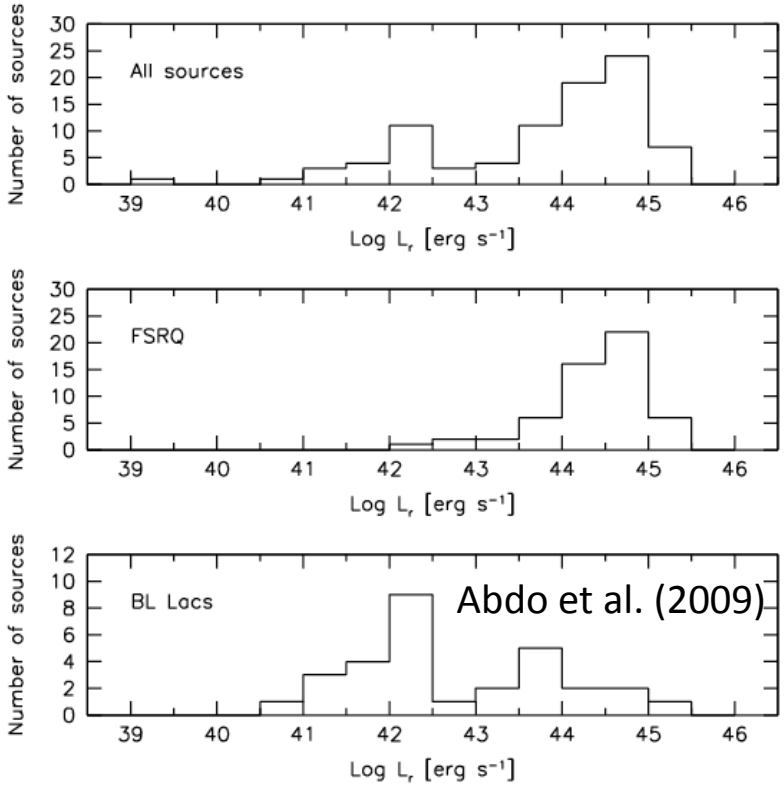
Low vs high radio frequency: luminosity-luminosity

- **Caveat: Distance dependence stretches distribution**
- **All cores more luminous than expected for RG of same P_{Low}**
  - **Doppler boost!**
  - **even more if one could subtract core from truly extended emission**
  - **indeed, extended radio emission of LBAS sources could be as low as 10^{23} W Hz^{-1}**



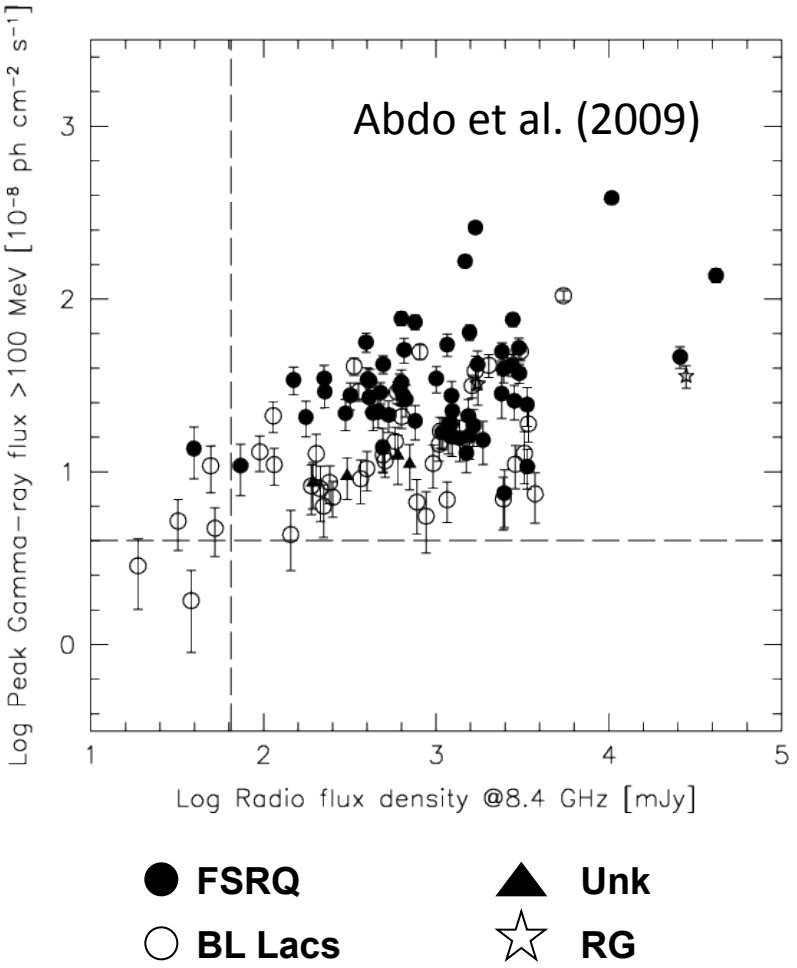
Radio luminosity according to type

- $L_r = \nu L(\nu)$, ν=8.4 GHz
- range $10^{39.1} < L_r < 10^{45.3}$ erg s^{-1}
- BL Lacs and FSRQ follow different distributions:
  - FSRQ: $\mathrm{Log}L_r = 44.4 \pm 0.6$ [erg s^{-1}]
  - BL Lacs: $\mathrm{Log}L_r = 42.8 \pm 1.1$ [erg s^{-1}]
- 2 RGs:
  - NGC1275 similar to BL Lacs: $L_r = 10^{42.2}$ erg s^{-1}
  - CenA lies at the very lower end of the radio power distribution, with $L_r = 10^{39.1}$ erg s^{-1}.



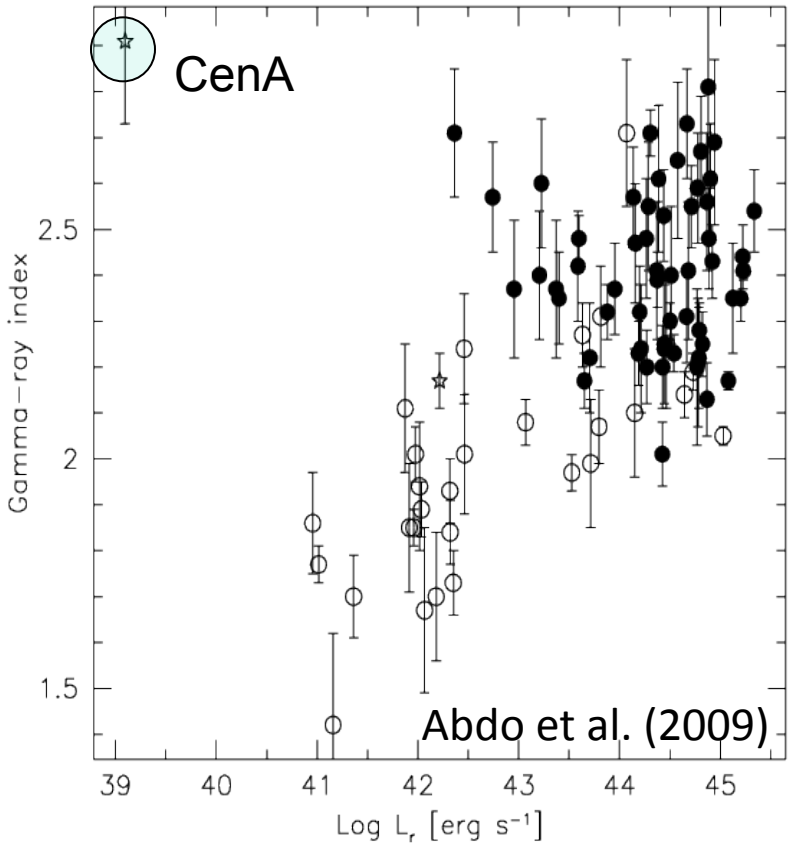
Radio vs gamma-ray flux

- Radio: CRATES f.d. at 8.4 GHz
- Gamma-ray: Fermi-LAT peak flux at E>100 Mev
- Spearman's r=0.42 (n=106) but…
  - Do few data points drive correlation?
    - Total without the most extreme data points goes down to r=0.24
  - BL Lacs and FSRQ sample rather different regions
    - FSRQ: n=57, r=0.19
    - BL Lacs: n=42, r=0.49
- Significance difficult to claim
  - issues of variability, extended radio emission, selection effects
- see also
  - talk on OVRO monitoring data by J. Richards with MC simulations
  - MOJAVE paper by Kovalev et al. 2009



Photon index vs radio luminosity

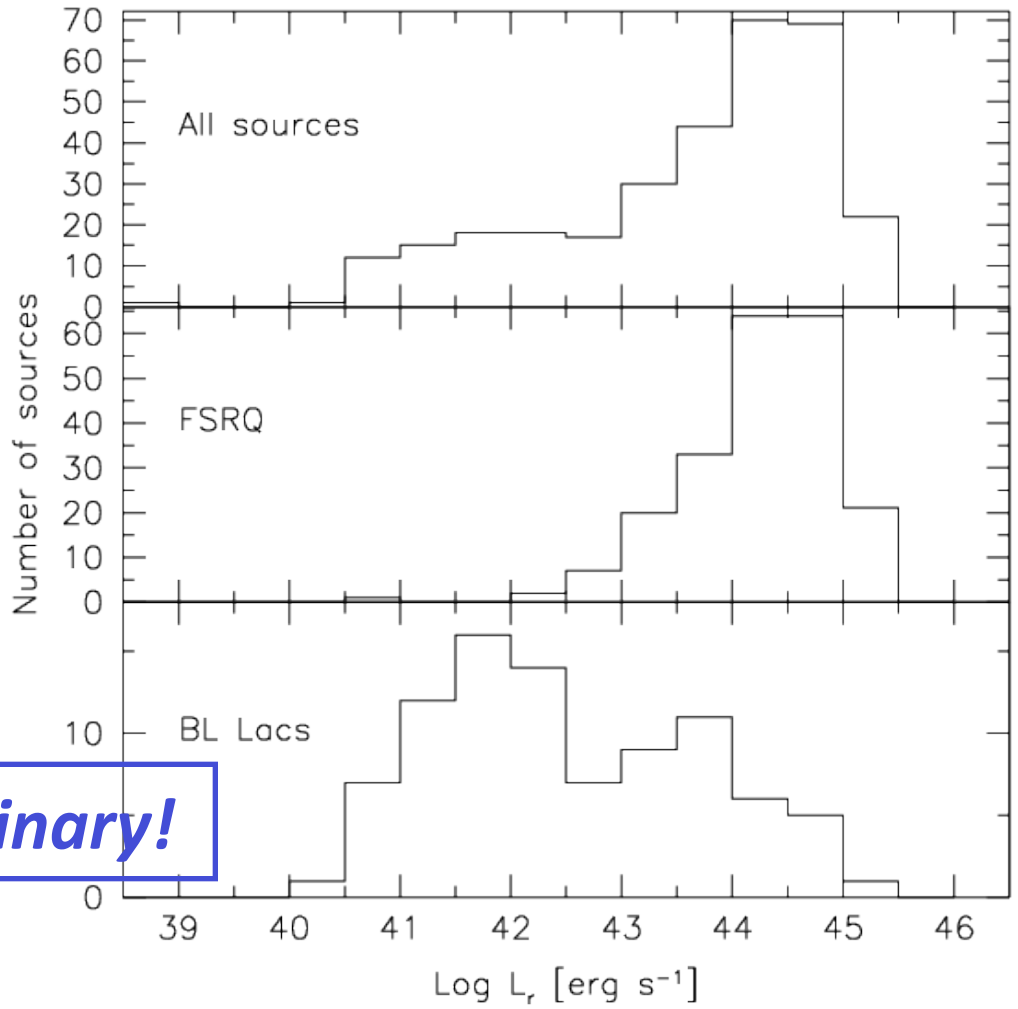
- Only sources with known redshift
  - K-corrected
- different source classes in different regions
  - FSRQs: largest Lr, softer indices
  - BL Lacs: lower Lr, harder indices
  - RGs: 3C84 BL Lac-like, CenA well displaced



Beyond the LBAS

- **LBAS results were restricted to**
  - **3 months of gamma-ray data**
  - **TS>100 (highest confidence gamma-ray sources)**
- **Fermi continues its operation in survey mode with unique capabilities:**
  - **Sensitivity: include the weakest gamma-ray (and radio?) sources**
  - **Field of view: gather data from as large sky area as possible**
  - **Spectral range: collect and discuss soft (radio bright?) and hard (radio weak?) sources**
- **In the 1 yr catalog under development from the LAT team, more than 1000 sources have been detected and characterized (see J. Ballet's talk)**
  - **Huge amount of work for classification and associations (see S. Healey's poster)**
  - **Several hundreds sources already classified – what does this sample look like in the radio?**

Radio luminosity



preliminary!

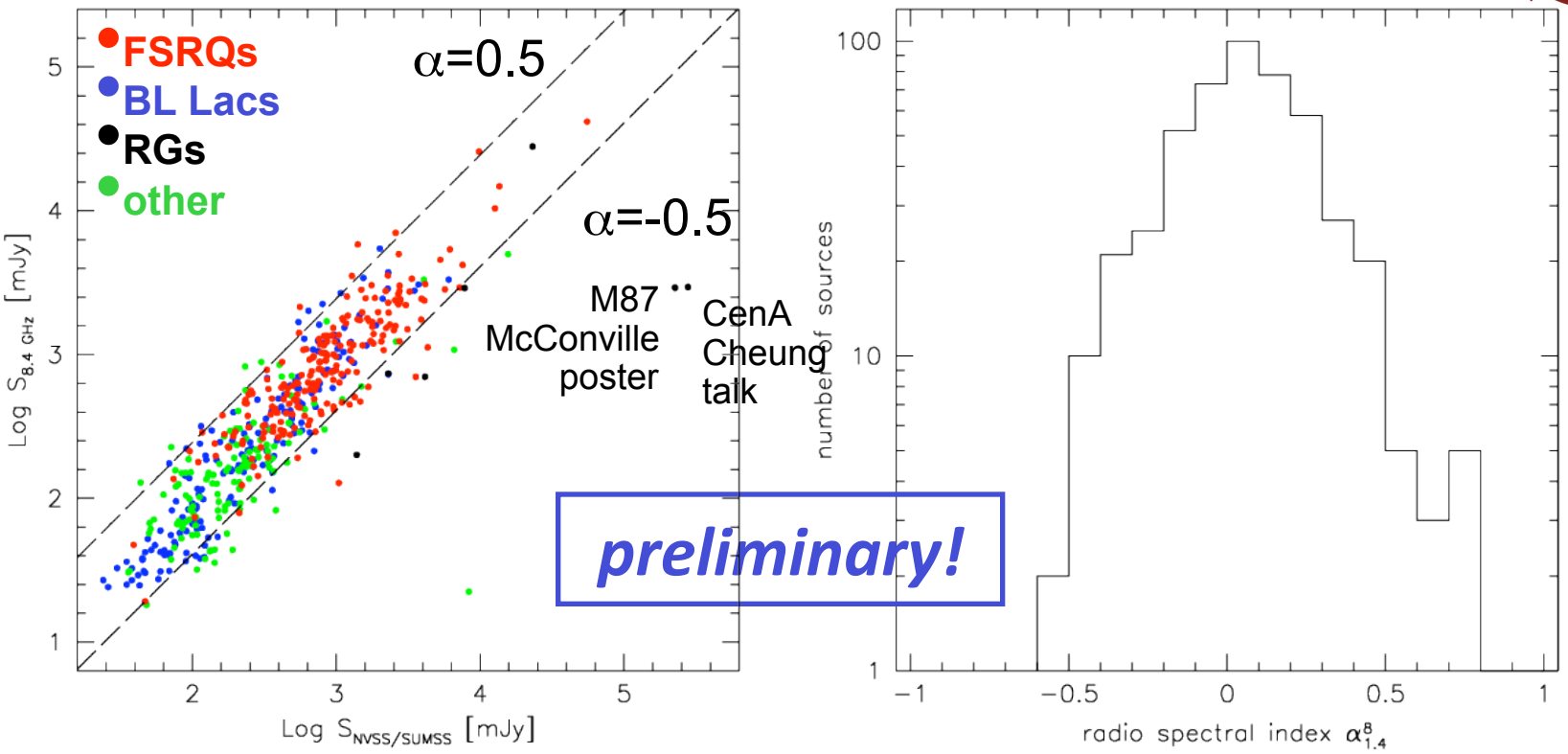
7 orders of magnitude, hundreds of sources

FSRQ:
44.2 +/- 0.7 [erg s-1]

BLLacs:
42.2 +/- 1.2 [erg s-1]
BIMODAL?

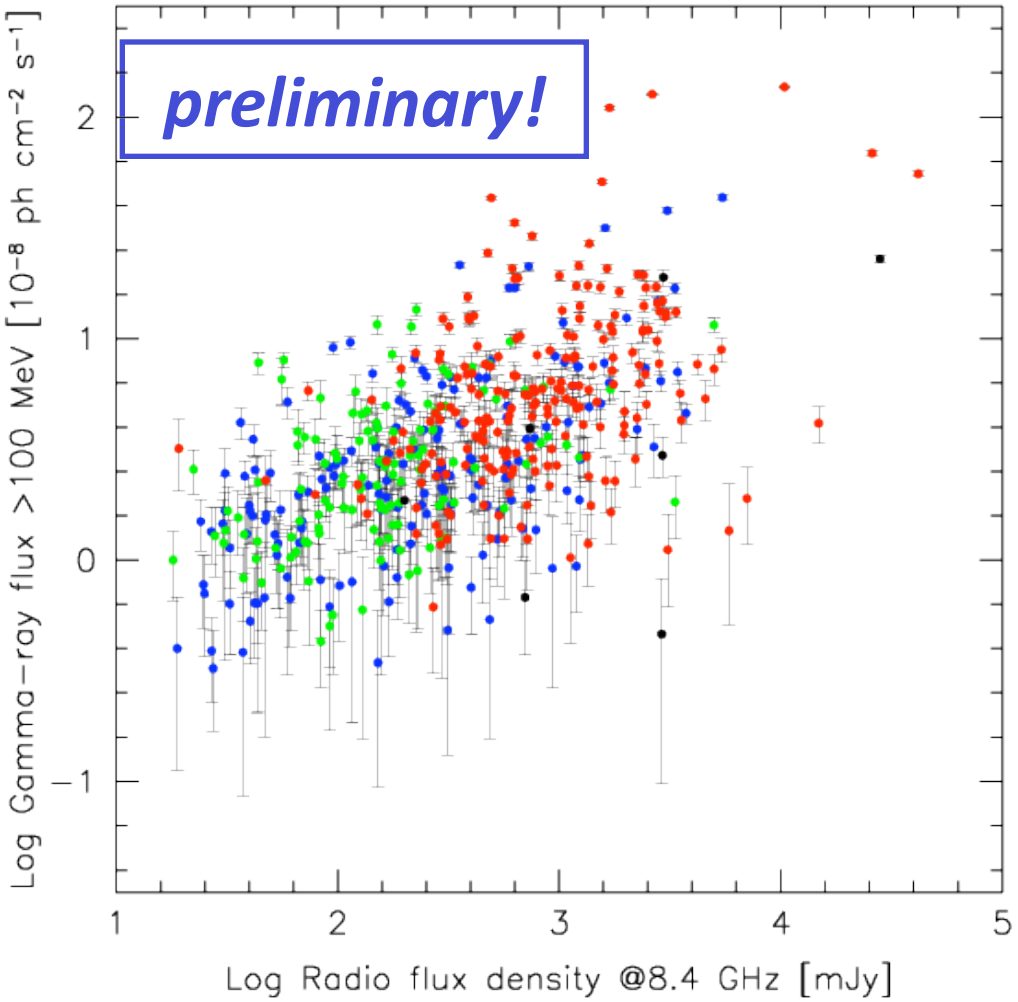
BL Lac numbers are lower because many lack redshift

Radio spectral index/core dominance



- **Sources with radio data at**
  - **1.4 GHz from NVSS: extended, optically thin radio emission**
  - **8.4 GHz from CRATES/NED: nuclear, self-absorbed emission**
- **Most sources with typical flat spectrum (<α> = 0.06+/-0.23)**
- **However, a small but non negligible fraction has α>0.5**
  - **SSRS, talk by E. Cavazzuti**

Radio vs gamma-ray fluxes



red: FSRQ
blue: BL Lacs
black: RGs
green: other

with more sources than in the LBAS, r=0.57

Take home notes

1. The gamma-ray extragalactic sky remains dominated by radio loud AGN

2. Blazars are by far the largest population but some steep spectrum radio sources are there

3. Radio and gamma-ray fluxes span 4 magnitudes, it's time for a rigorous assessment of significance of their correlation – or lack thereof

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