CLUSTERING MEASUREMENTS OF ACTIVE GALACTIC NUCLEI I

ENVIRONMENTS OF BL LAC AND FSRQ BLAZARS USING GALAXIES FROM THE SDSS

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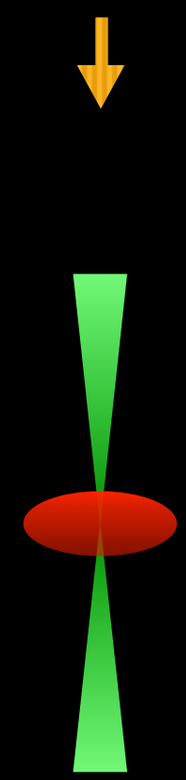
Mrk 421 (NASA/STScI)

BLAZAR/RADIO GALAXY UNIFICATION SCENARIO

	BL LAC	FSRQ
OPTICAL SPECTRUM	no strong emission or absorption features EW < 5 Å	broad emission lines superimposed on strong continuum
RADIO JETS	high $\nu_{\rm peak}$	low $\nu_{\rm peak}$, $\alpha_r < 0.5$ core-dominated morphologies
HOST GALAXY	luminous ellipticals	luminous elliptical, 1-2 mags brighter than BL Lac hosts
ENVIRONMENT	moderately rich clusters; Abell class 0 to 1	lie in regions of lower galaxy densities

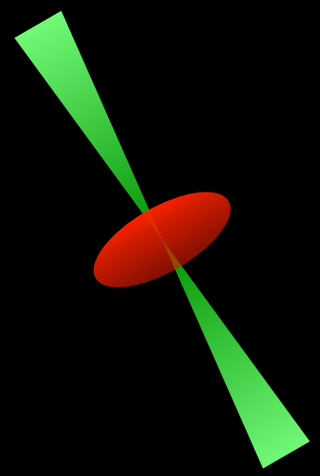
VIEWED DIRECTLY DOWN JET AXIS



BLAZAR/RADIO GALAXY UNIFICATION SCENARIO

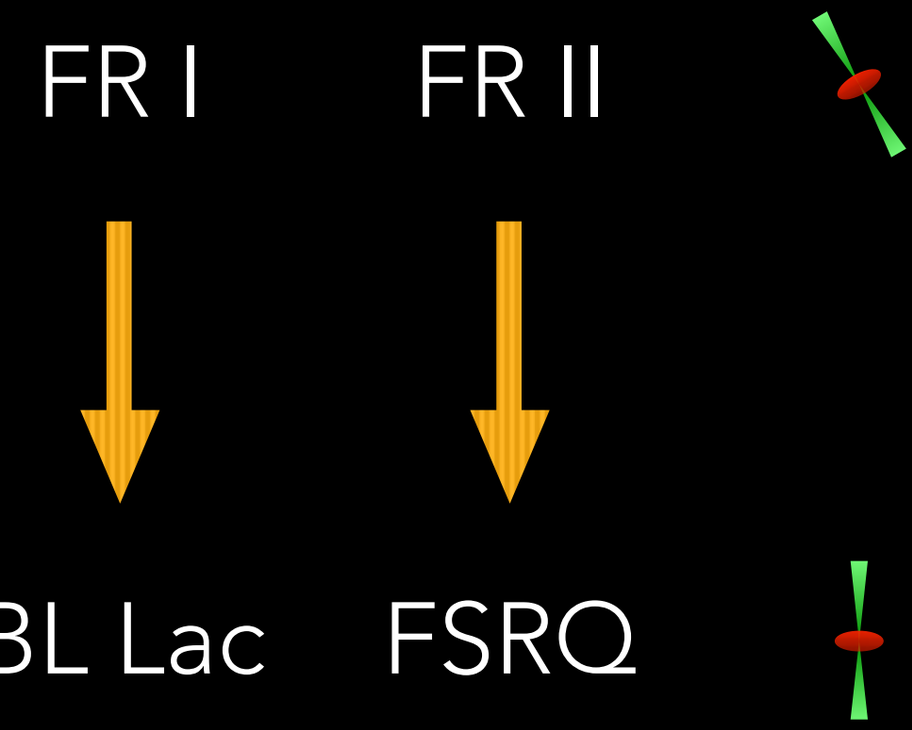
	FR I	FR II
OPTICAL SPECTRUM	weak optical emission lines (for given luminosity)	typically stronger optical emission lines
RADIO JETS	low-luminosity; intensity falls off away from nucleus	high luminosity; extended lobes and hotspots
HOST GALAXY	giant ellipticals; 10% have some deviation from profile of $r^{1/4}$	ellipticals; slightly lower average optical luminosities than FR Is
ENVIRONMENT	moderately rich clusters; often BCGs	relatively isolated, more consistent with field galaxies

VIEWED OFF-AXIS FROM RADIO JET



PREVIOUS RESULTS

- Prestage+88: BL Lac environments are consistent with FR Is
- Individual studies of BL Lacs show excesses of galaxies with Abell richnesses between 0 and 1 (Falomo+96,00,Pesce +94,Fried+93,Smith+95) in agreement with FR Is (Hill+91)
- Owen+95: surveys of powerful radio sources in clusters revealed many FR Is, but no BL Lacs.
- Wurtz+93,97: BL Lacs are found in poor clusters, with richness increasing with redshift. Trends are more similar to FR II than FR I.
- Urry+00, Falomo+00, Pesce+02: enhancements in BL Lac environments over average density. High number of close companions (< 20 kpc) identified.



MISSING: UP-TO-DATE STUDIES OF THE BLAZAR POPULATIONS WITH IMPROVED STATISTICS AND DEEPER IMAGING

SPATIAL COVARIANCE AMPLITUDE

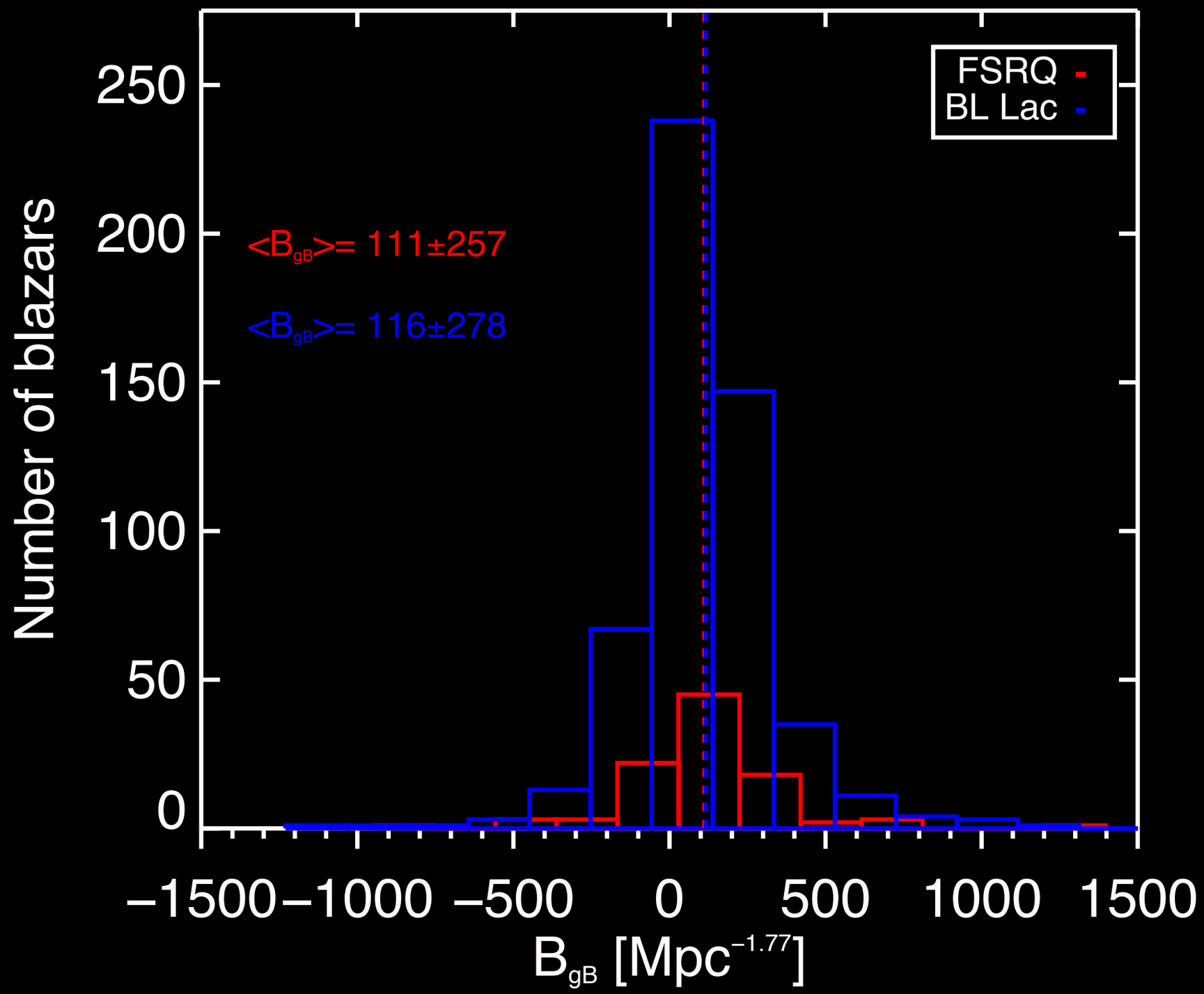
- Developed by Longair & Seldner (1979)
- Measures number of neighboring galaxies in projection around a single point
- Pros: independent of magnitude limit or counting radius; can be used without full 3D positions
- Cons: statistical measurement with large error bars (~50-100%) on individual points

$$B = (N_t - N_{bg}) \frac{(3-\gamma) D^{\gamma-3} \theta^{\gamma-1}}{2 A_\theta I_\gamma \Psi[M(m,z)]}$$

SAMPLE SELECTION

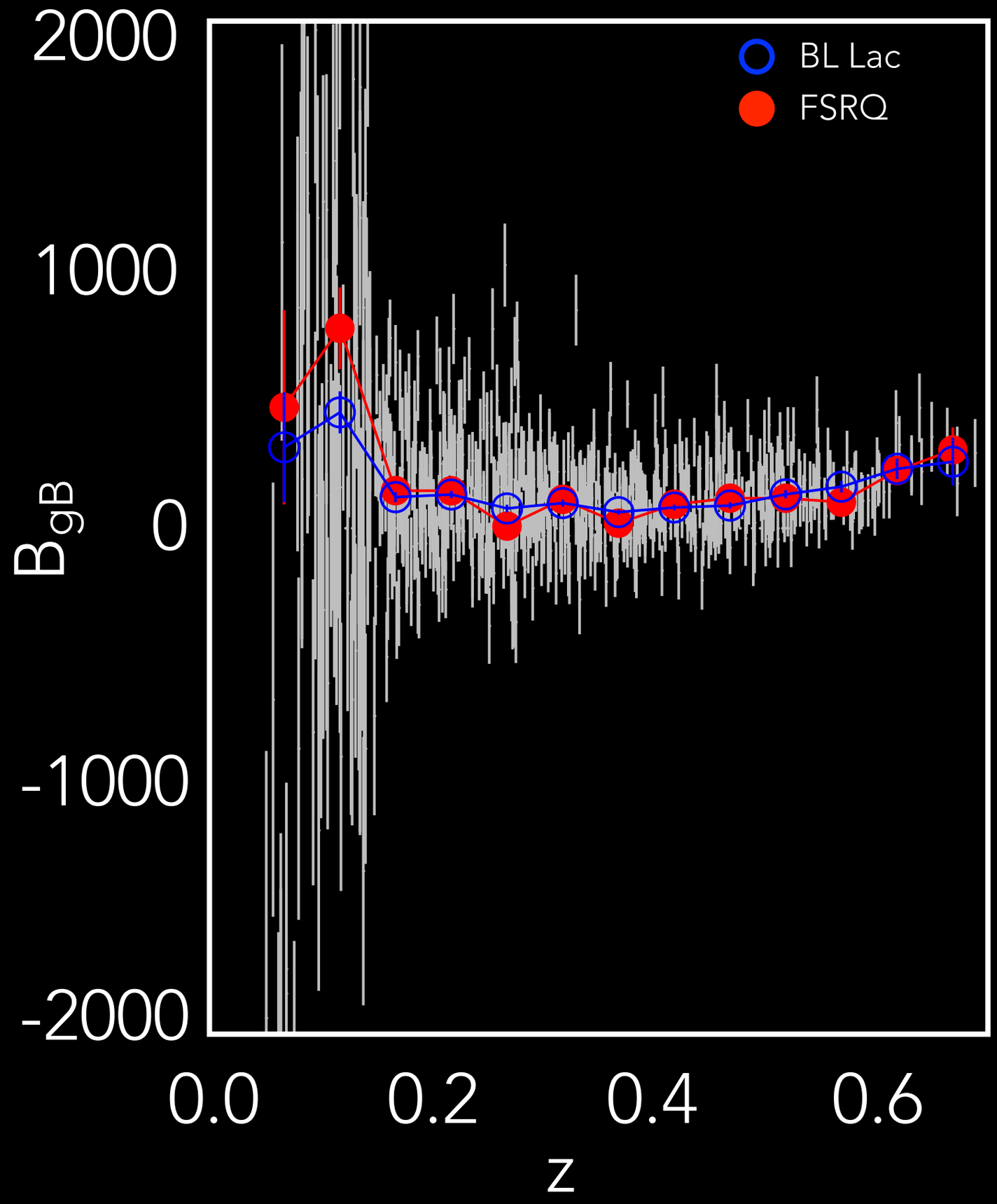
- Roma-BZCAT (2,728 blazars)
- Optically-selected blazars from SDSS
  - 723 BL Lacs (Plotkin et al. 2010)
  - 185 FSRQs (Chen et al. 2009)
- TeV-Cat γ-ray selected objects (148 blazars)

DISTRIBUTION OF BLAZAR SPATIAL CORRELATION AMPLITUDES

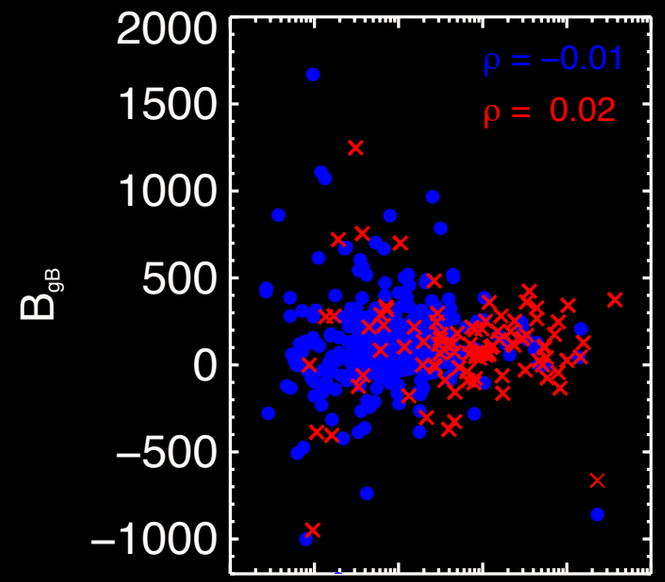


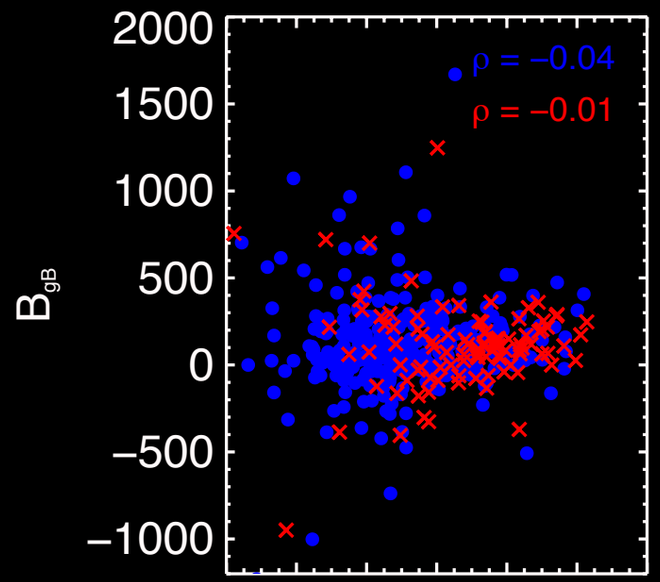
BLAZAR CLUSTERING AS FUNCTION OF REDSHIFT

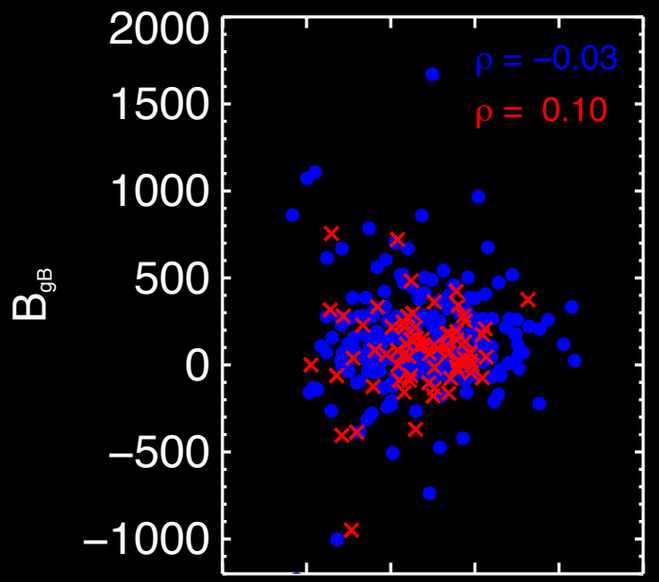
- 757 blazars have measurable B_{gB} values from SDSS data
- Richer clusters are found at $z > 0.5$, increasing by a factor of 2-3
- Trend is the same for both BL Lacs and FSRQs

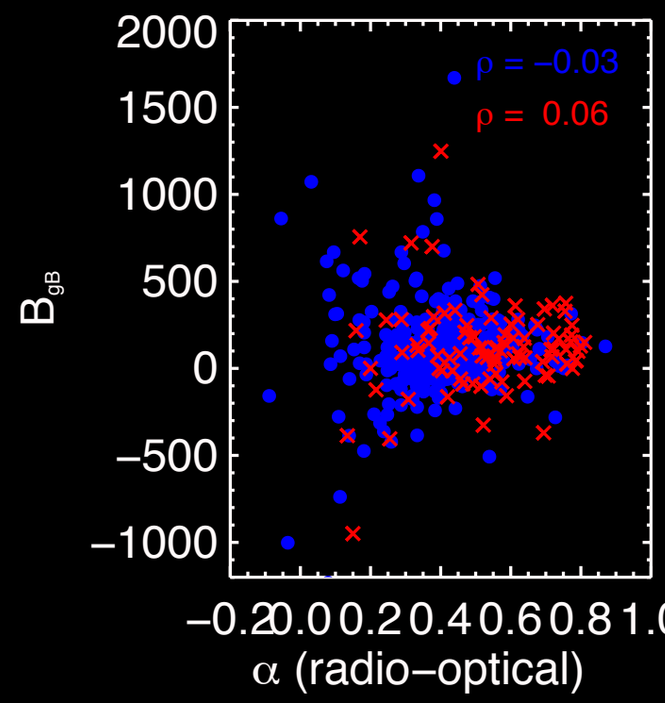


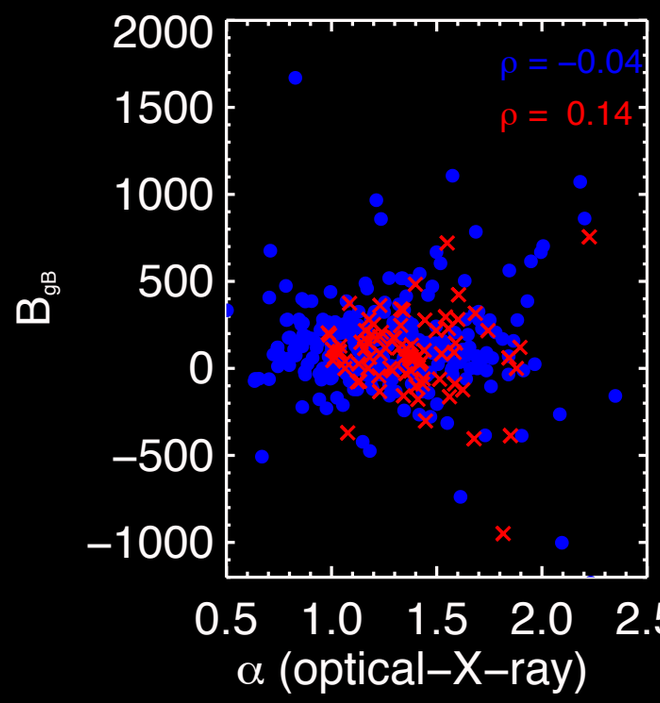
CLUSTERING VALUES AS FUNCTION OF MULTI WAVELENGTH PROPERTIES

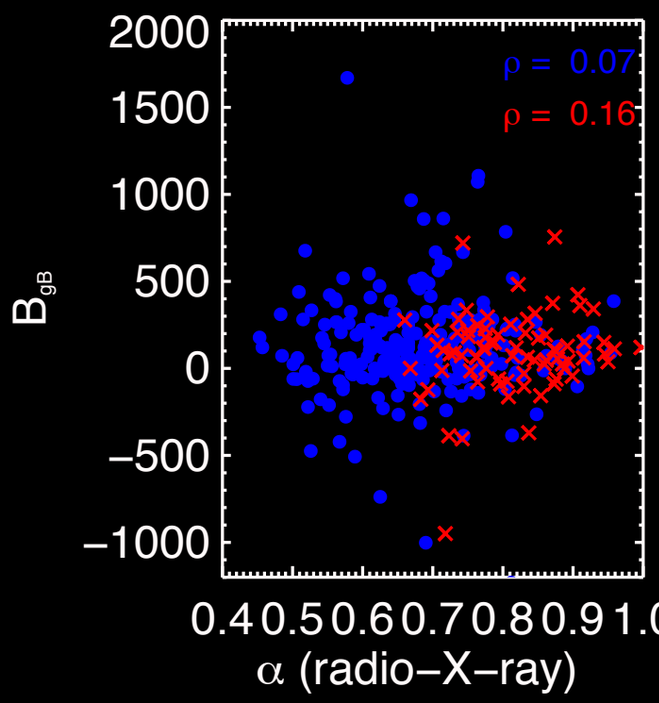




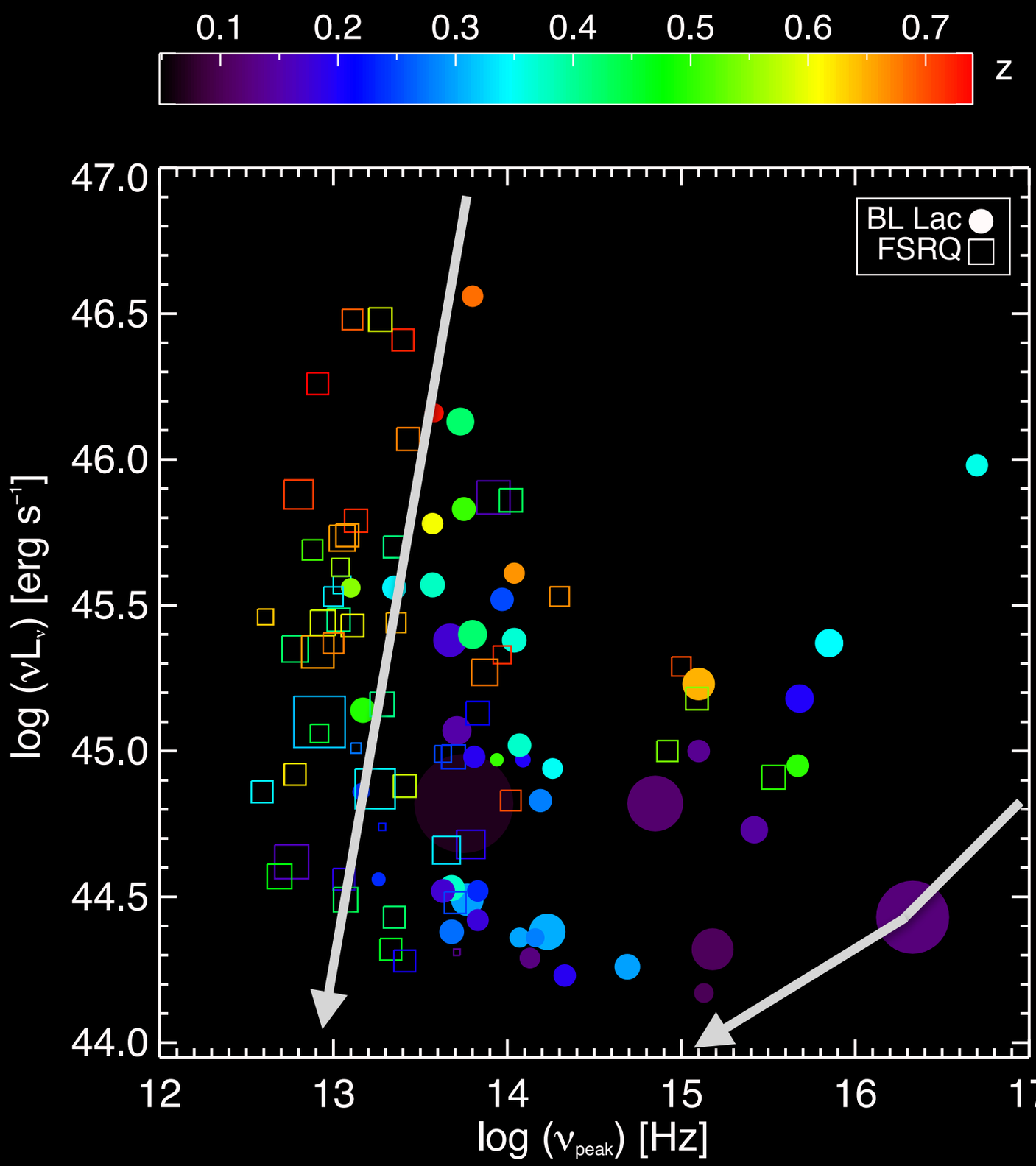




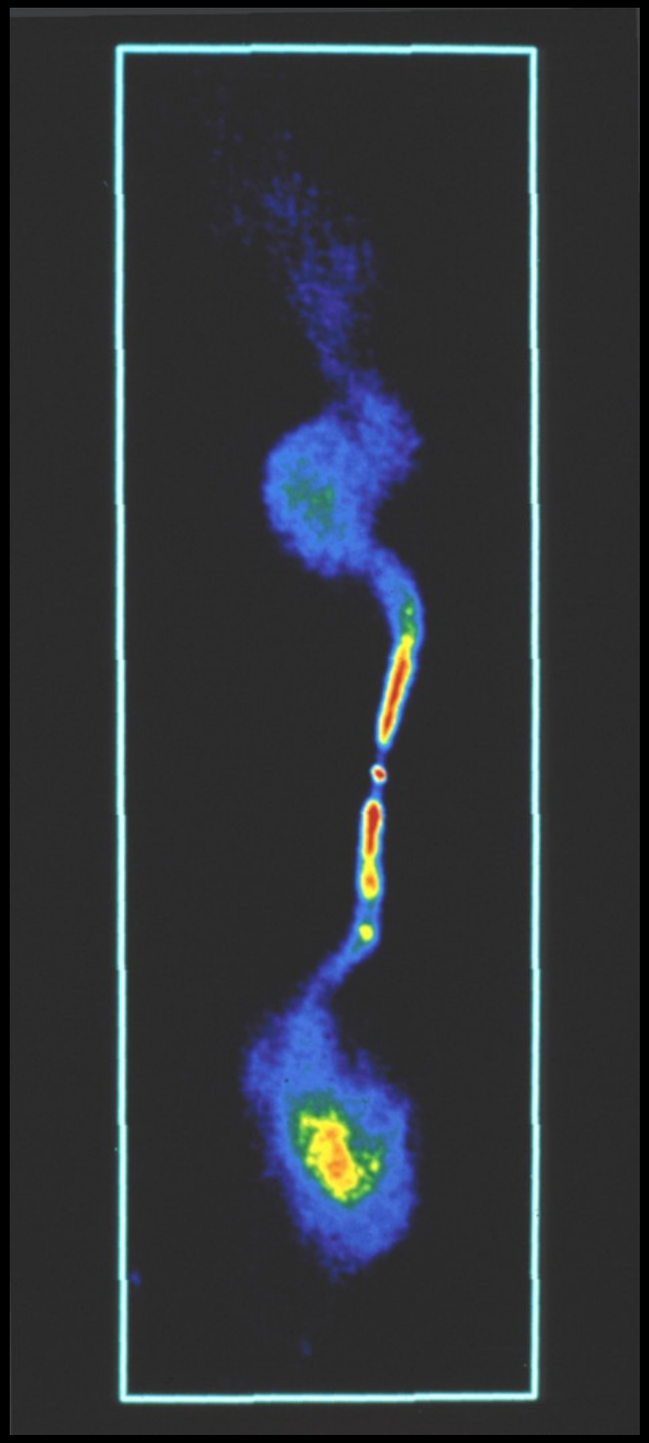


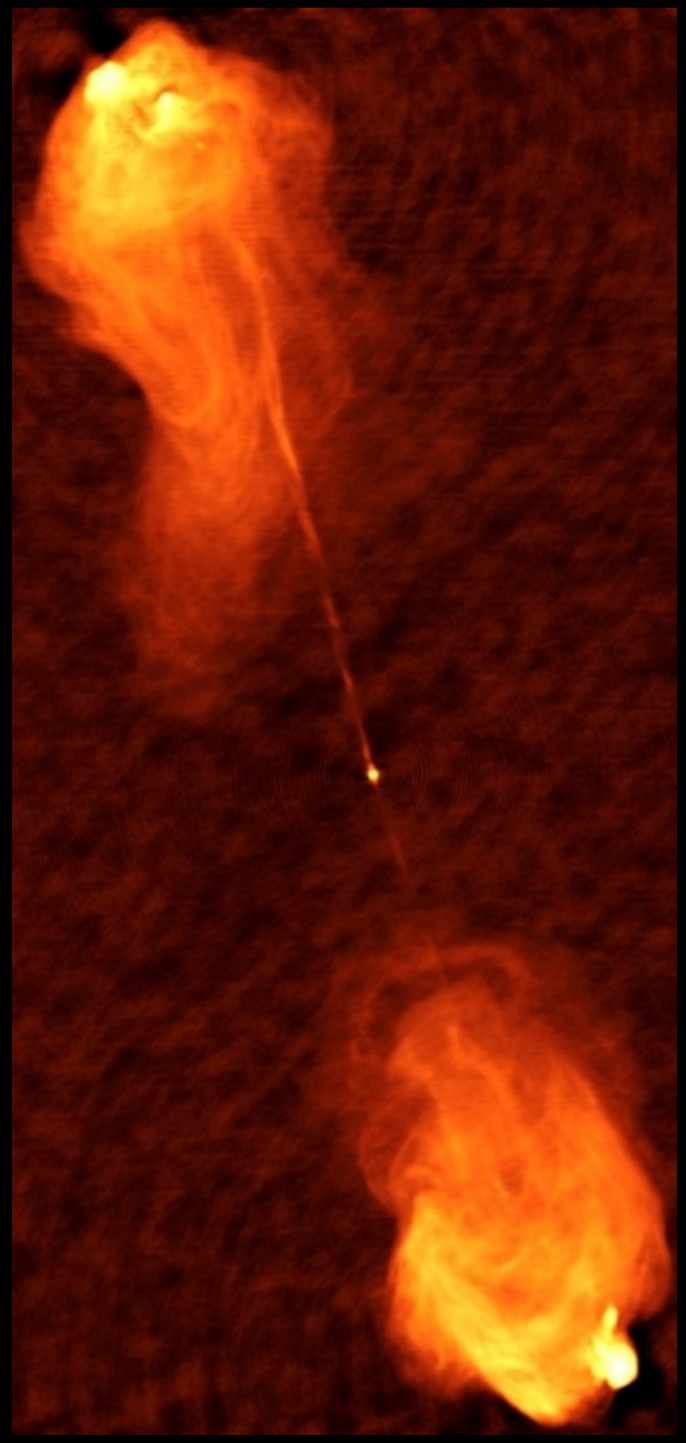


CLUSTERING AND THE BLAZAR SEQUENCE/ENVELOPE



ENVIRONMENTS OF POWERFUL RADIO GALAXIES



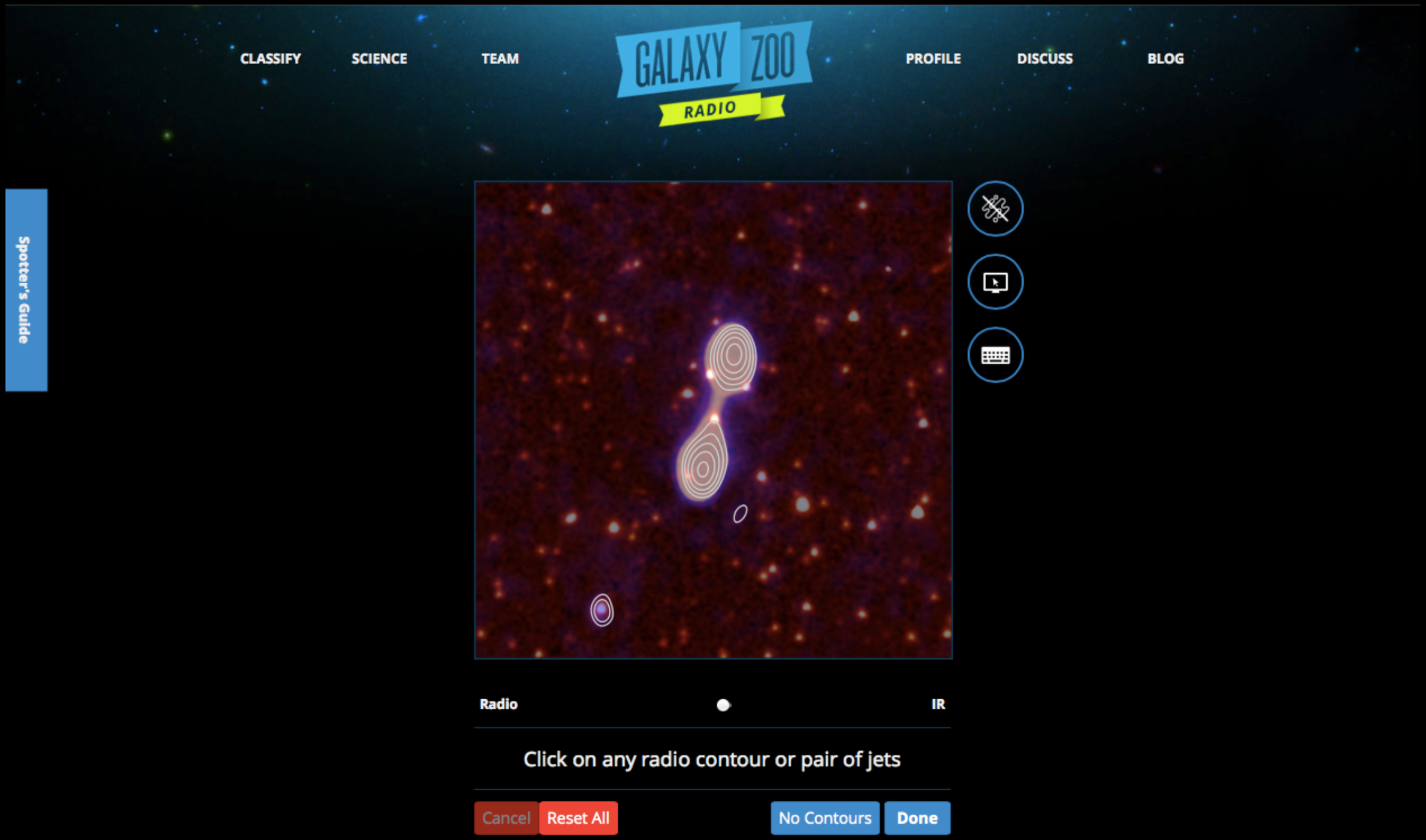


3C449, Cyg A images courtesy AUI/NRAO

- Measured B_{gg} for 239 morphologically-classified radio galaxies in the SDSS footprint
- Radio galaxies have similar spatial correlation amplitudes to both types of blazars
  - FR I: 150 ± 533 Mpc$^{-1.77}$
  - FR II: 175 ± 364 Mpc$^{-1.77}$
- FR I galaxies exist in similar environments to FR II galaxies
- No strong evolution in B_{gg} as a function of redshift

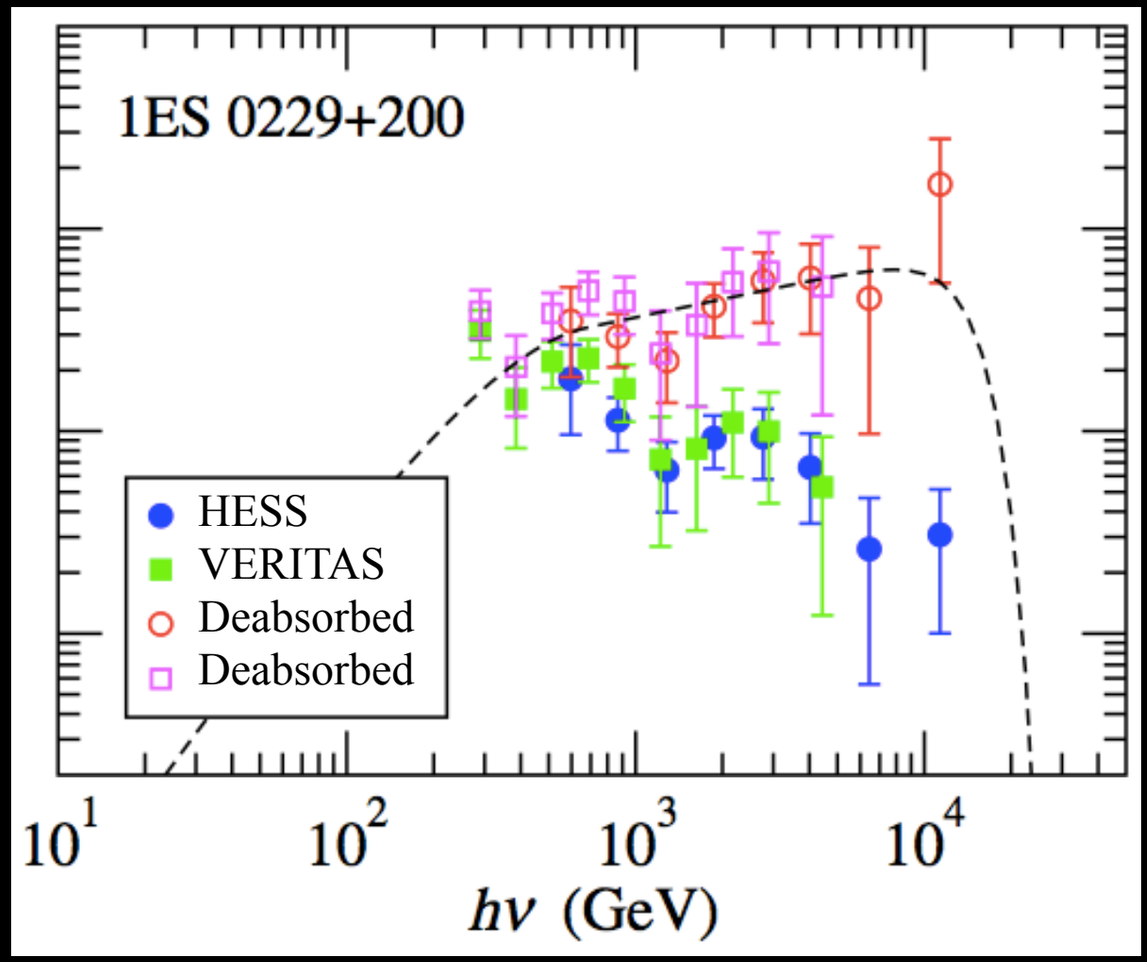
EXPANDING THE SAMPLE SIZE

RADIO GALAXY ZOO



VARIABILITY AS FUNCTION OF ENVIRONMENT

- Galaxies with UHECR emission can only show it if magnetic fields are not isotropized by nearby companions
- Emission caused by UHECR should not rapidly vary in flux, since the source size is large.
  - Prediction: low variability TeV blazars should live in low-density environments.
- Of the two known TeV blazars in SDSS with low variability, one is in a an underdense and the other in a moderately overdense cluster



Razzaque+12

	z	*B*
1ES 0229+200	0.14	-299 ± 259
RGB J0152+017	0.08	316 ± 366

PHYSICAL MECHANISMS FOR DIFFERENT BLAZAR CLUSTERING STRENGTHS

- Rapidly changing gas density or galaxy-galaxy interaction rate causes cause AGN in rich clusters to fade. This would transform more quasars into BL Lacs.

- FR II sources are less likely to be in high-density environments; increased external gas pressure in ICM suppresses collimated jet with advancing hot spot

- Inflow of gas/dust from nearby neighbors/ICM changes the accretion efficiency of the BH

CONCLUSIONS

- The unification paradigm of blazars with radio galaxies can be indirectly probed by examining their Mpc-scale environments
- 757 blazars + clustering galaxies from SDSS is the largest sample so far constructed
- Blazars exist in moderately over-dense regions, but there is no significant difference between companions of the BL Lac and FSRQ populations