Blazar Radio and Optical Survey (BROS): Catalog of Blazar candidates

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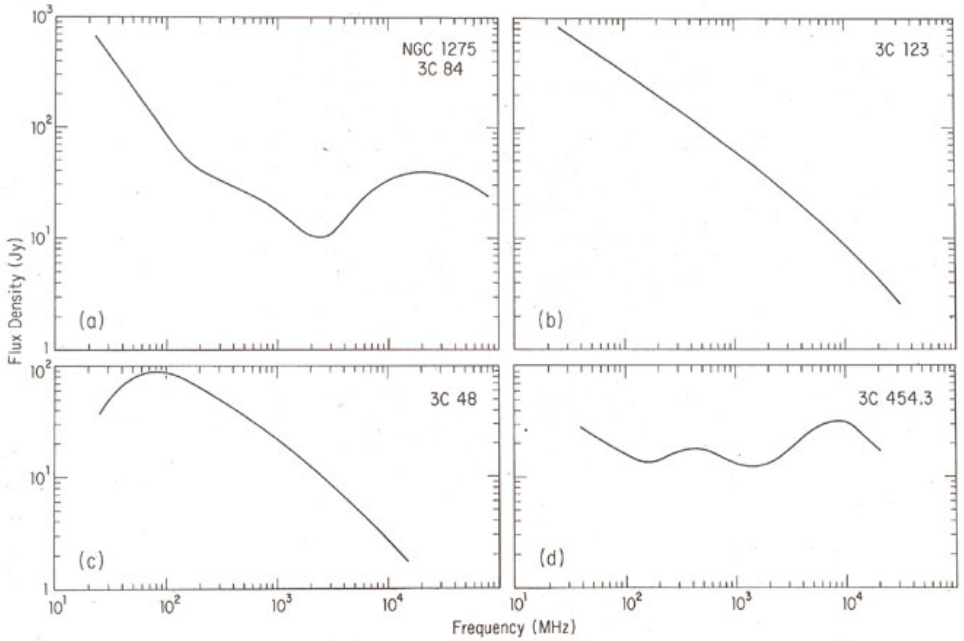
Outline

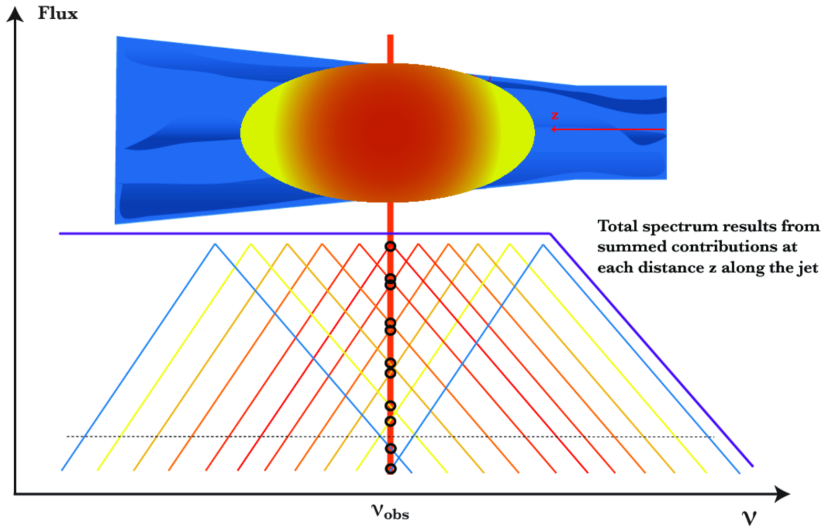
1. Blazars in radio band
2. Previous CRATES blazar candidate catalog (Healey+07)
3. Details of our BROS catalog
    - ✓ Presence of two distinct populations: “quasar-sequence” and “elliptical-sequence”
4. Summary and perspectives for future TeV survey

Blazars in radio band

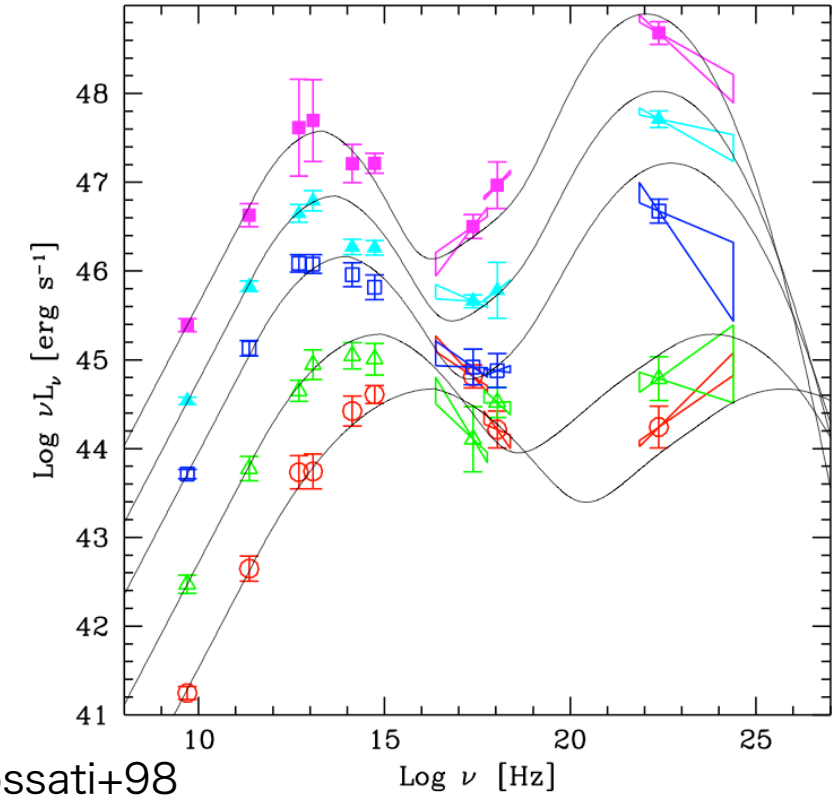
Radio spectra
of radio galaxies
and blazars
(Longair 2011)



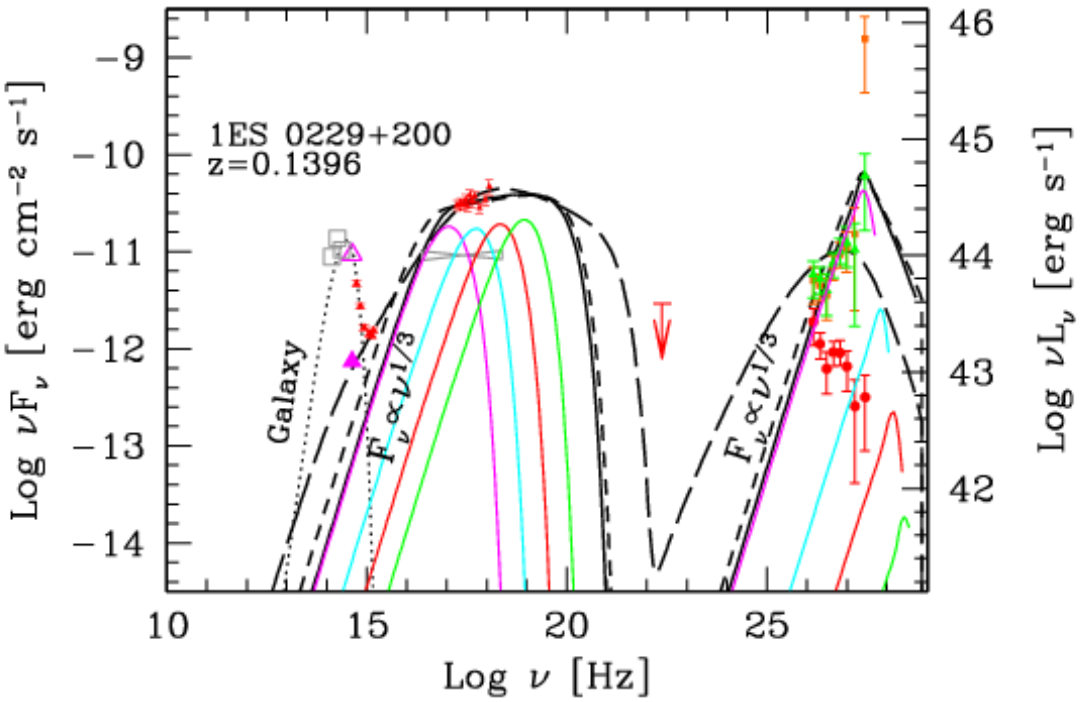
- Compact and flat spectrum of $\alpha > -0.5$ ($F_\nu \propto \nu^{\alpha}$)
- Flat radio spectrum is caused by superposition of self-absorbed synchrotron emission regions (e.g., Markoff+10)
- **Flat radio spectrum is the key to select blazars**



Blazar SED and extreme HBL population



Fossati+98

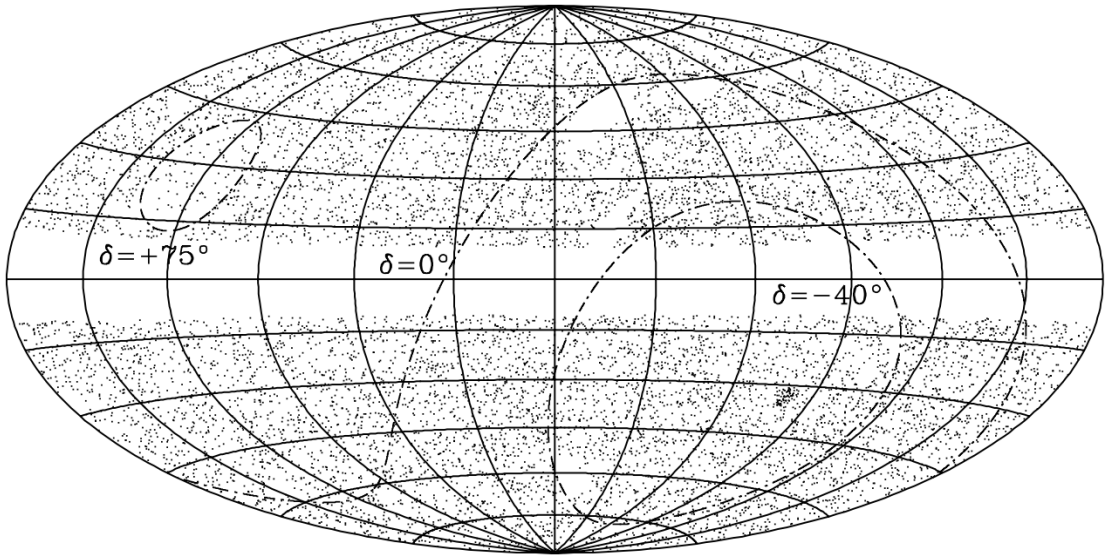


Tavecchio+09

- Fainter blazars show higher peak frequency (known as blazar sequence)
- Optical emission of some nearby (z<~0.3) faintest BL Lac objects (extreme HBLs) are dominated by host galaxy because of the faint jet emission (e.g., 1ES 0229+200)
- Extreme HBLs are important objects to study intergalactic magnetic field as well as particle acceleration (large minimum electron Lorentz factor and low magnetic field)
- They are hard TeV emitter, so before CTA observation, we want to pick up eHBL candidates

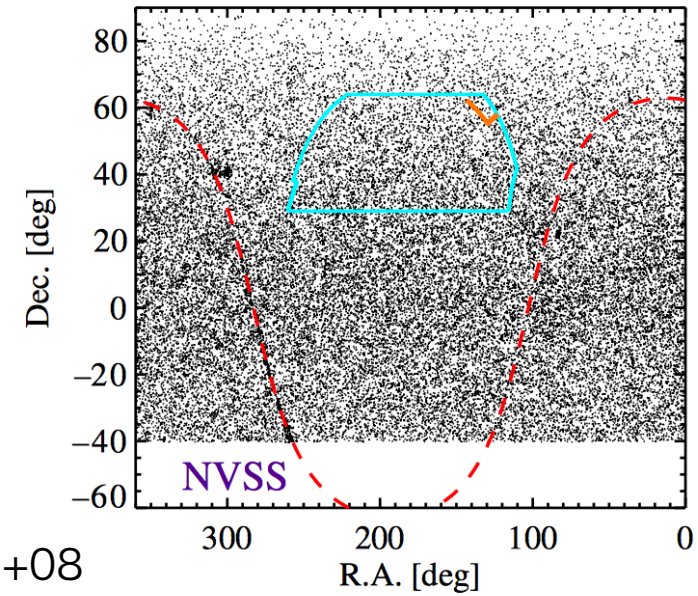
CRATES blazar candidate catalog (Healey et al. 2007)

- Flat radio sources at 1.4 GHz, 4.8 GHz and 8.4 GHz using NVSS, GB6, and VLA archives
- 11131 sources with $F_{4.8GHz}$ > 65 mJy and located at |b|>10 deg
- It has been used to identify Fermi MeV/GeV blazars and unIDs at high Galactic latitude



NVSS (NRAO VLA Sky Survey) and TGSS catalogs

	NVSS	TGSS
Frequency and telescope	1.4 GHz with VLA	150 MHz with GMRT
Survey region	δ >-40 deg	δ >-53 deg
Source number	2 million	0.62 million
Angular resolution	45''	25''
Sensitivity	>2.5 mJy (almost uniform)	>~10-20 mJy (non-uniform)



Kimball+08

Source distribution

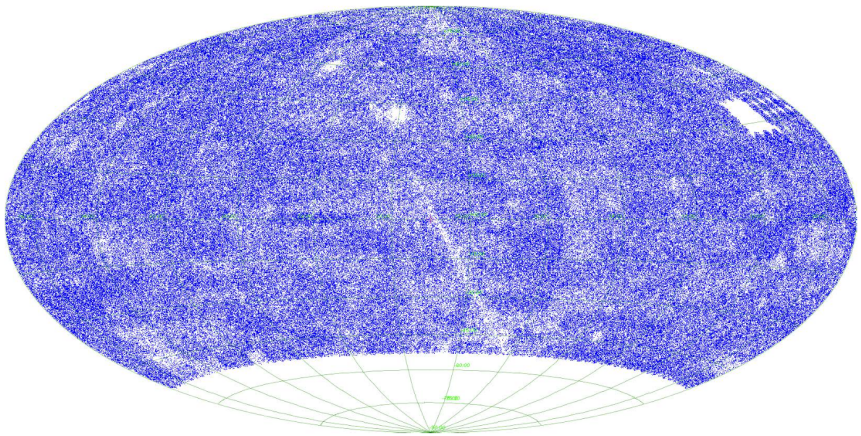
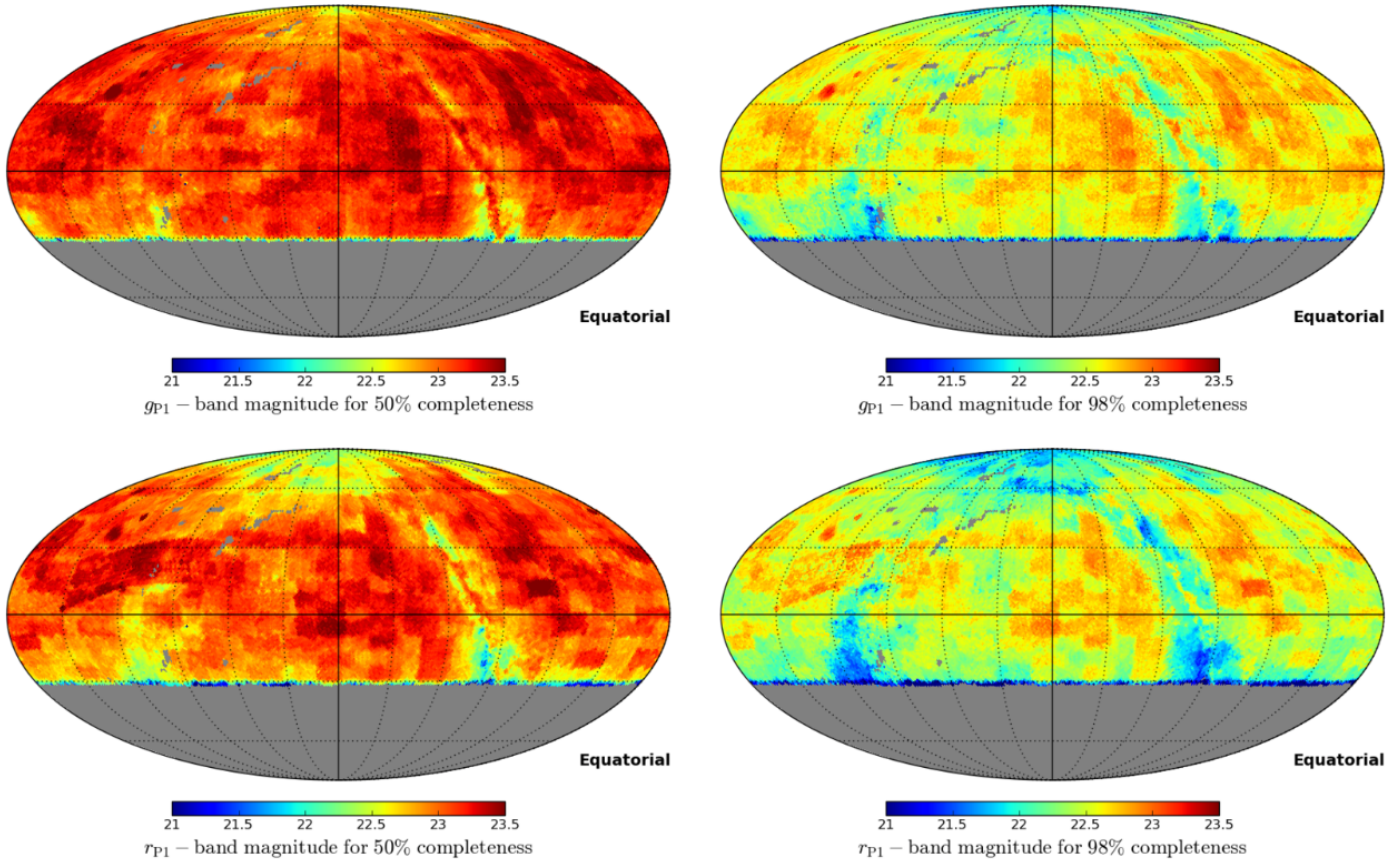


Fig. B.2. As Figure B.1, but now marking the spatial distribution of the 623,604 extracted sources in this data release. The extracted source density is correlated with the background RMS noise distribution as depicted in Figure 8.

Intema+16

Pan-STARRS1 optical survey

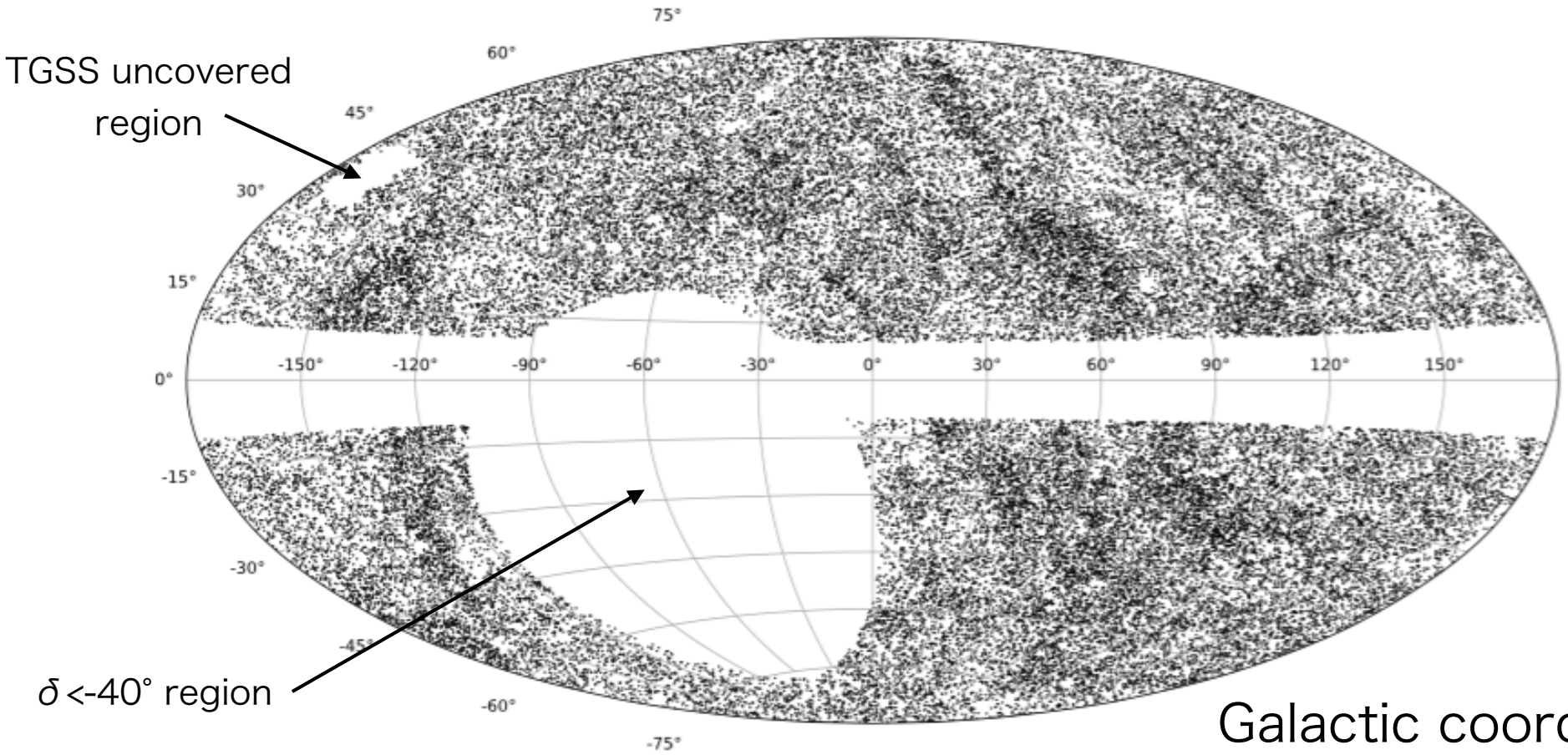
- 3pi sky survey with grizy limiting magnitudes of 23.3, 23.2, 23.1, 22.3, 21.4, respectively
- Typically 1 magnitude deeper than SDSS photometric survey
- Highest sensitivity covering the large region of δ>-30 deg



Chambers et al. 2017

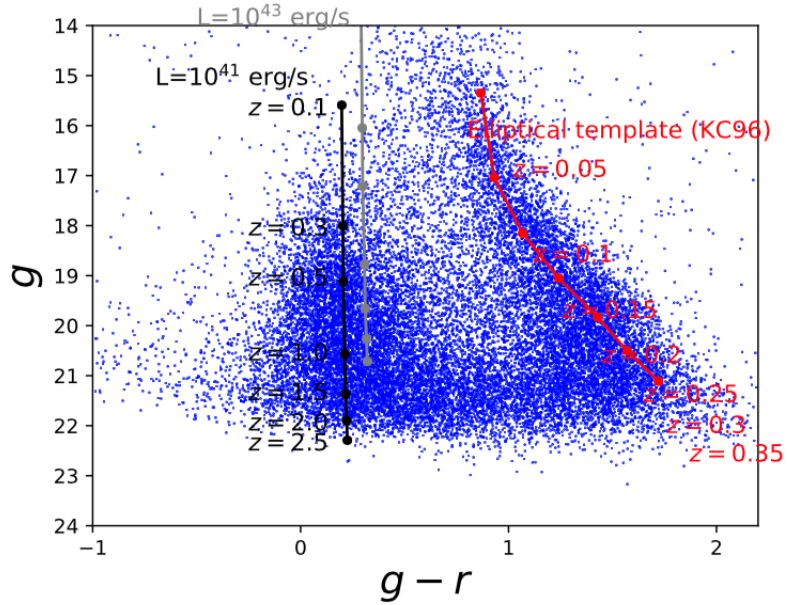
Sky distribution

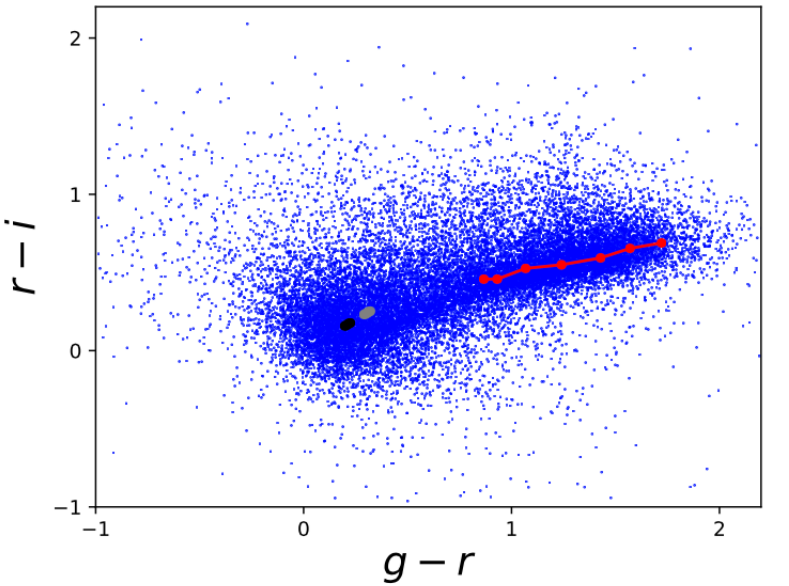
- We picked up 56314 flat-spectrum radio sources (i.e., blazar-candidates) located at |b|>10 deg and δ>-40 deg
- Non-uniform distribution is not intrinsic but artificial due to non-uniform sensitivity of TGSS survey



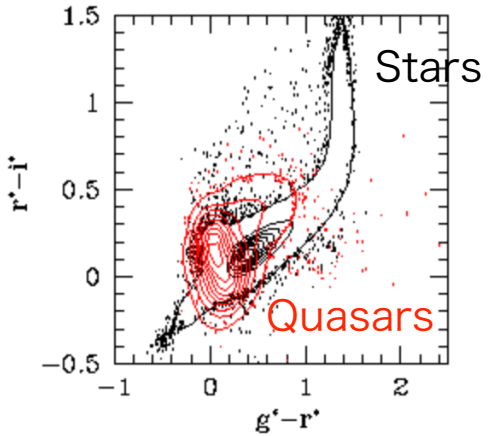
Galactic coordinate

PS1 optical counterparts



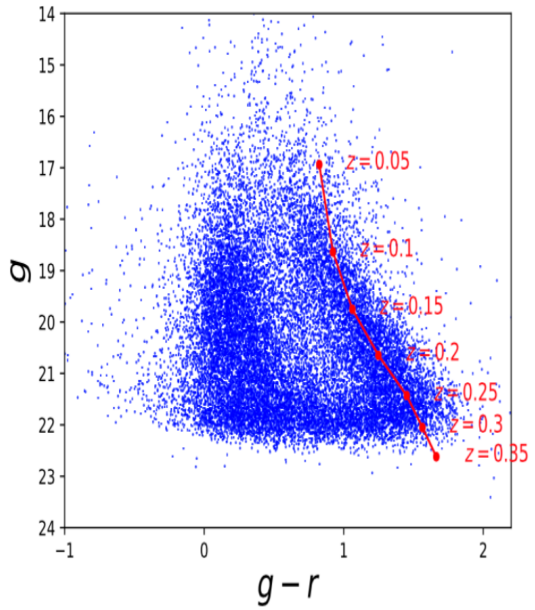


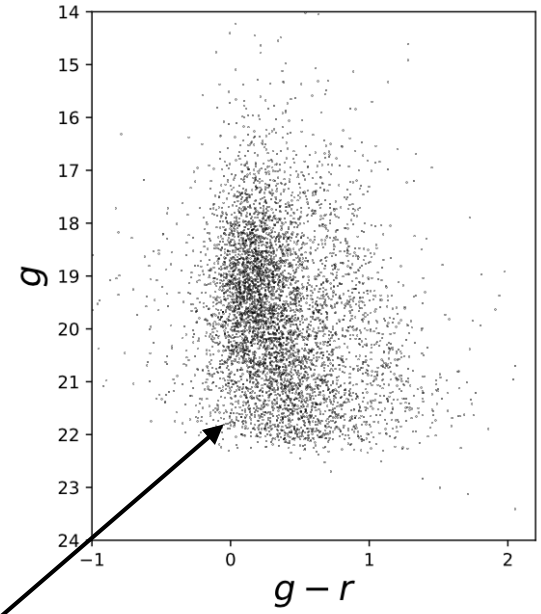
- Among 56314 BROS sources, 35666 sources have PS1 counterparts in either of the grizy bands (Preliminary)
- For sources detected in gri bands, we made color-color and color-mag plots
- 2 populations are present:
  - ✓ Quasar-like (including blazar population)
  - ✓ Elliptical galaxy-like
- Elliptical galaxy templates of M=-21.5 at z<~0.3 well represents the “elliptical sequence”

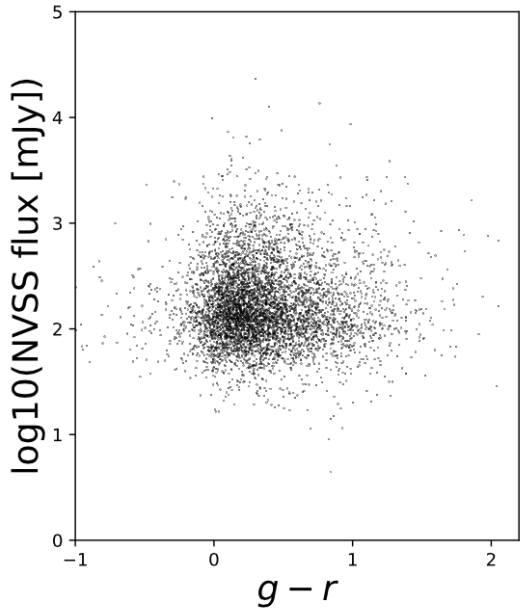


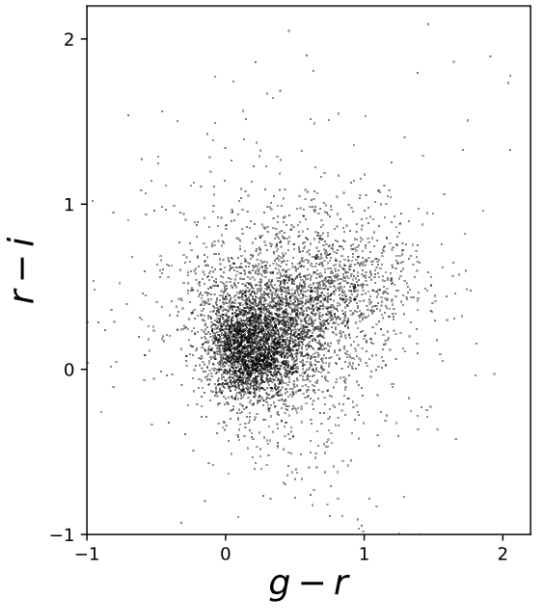
g-r vs r-i plot
for SDSS quasars
(Stoughton+02)

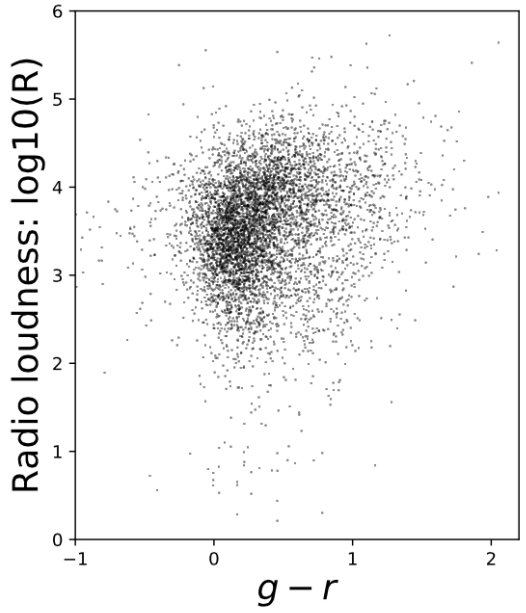
CRATES-PS1 cross matching





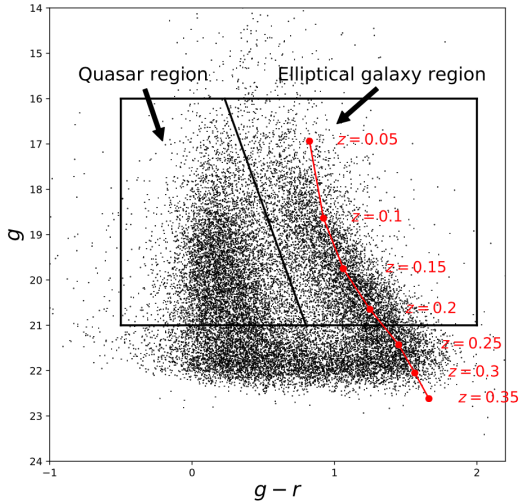




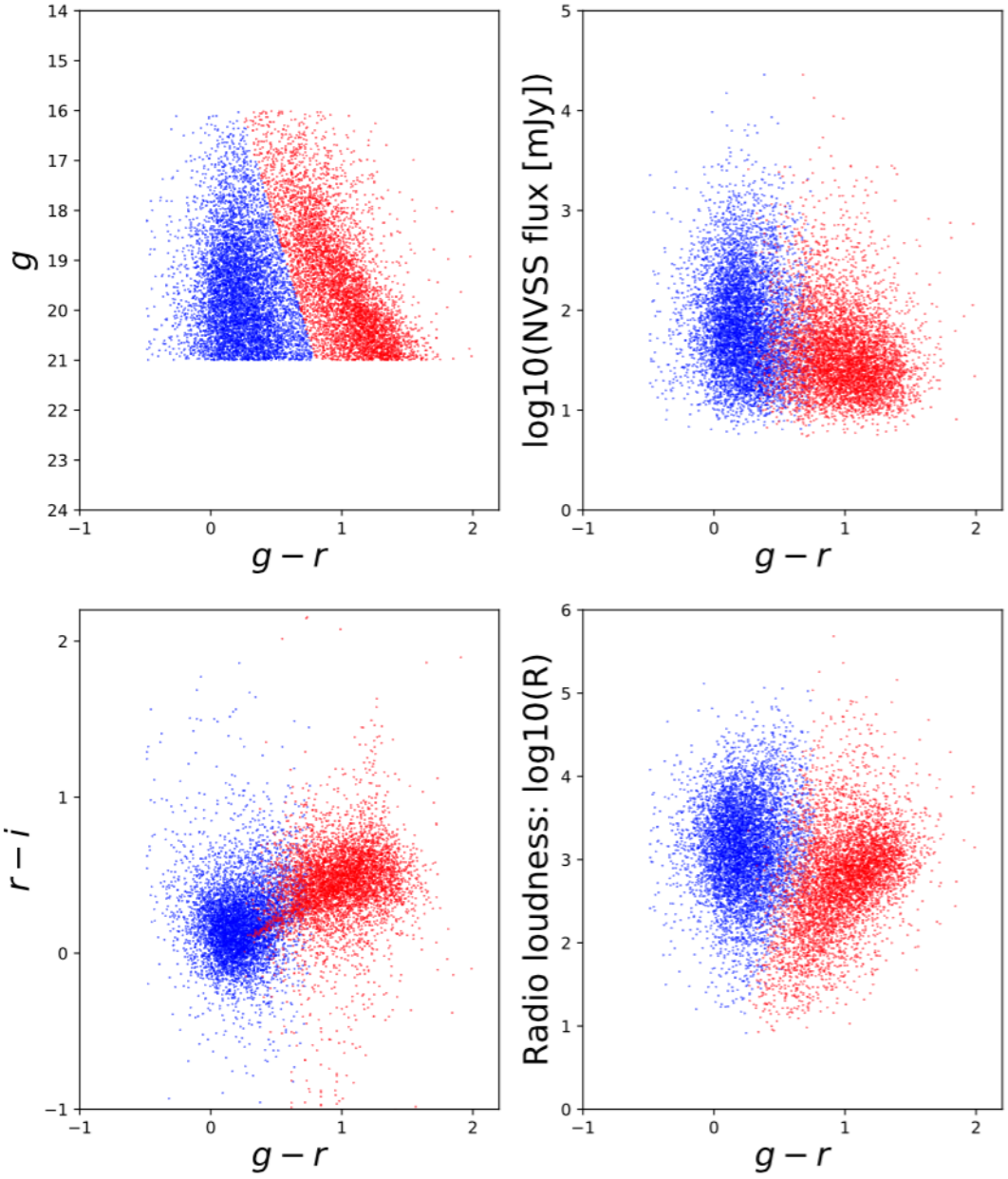


- Quasar-sequence is seen for CRATES-PS1 sample
- But elliptical-sequence is not present, possibly due to high radio flux threshold ($F_{4.8GHz}$ > 65 mJy)

Radio properties

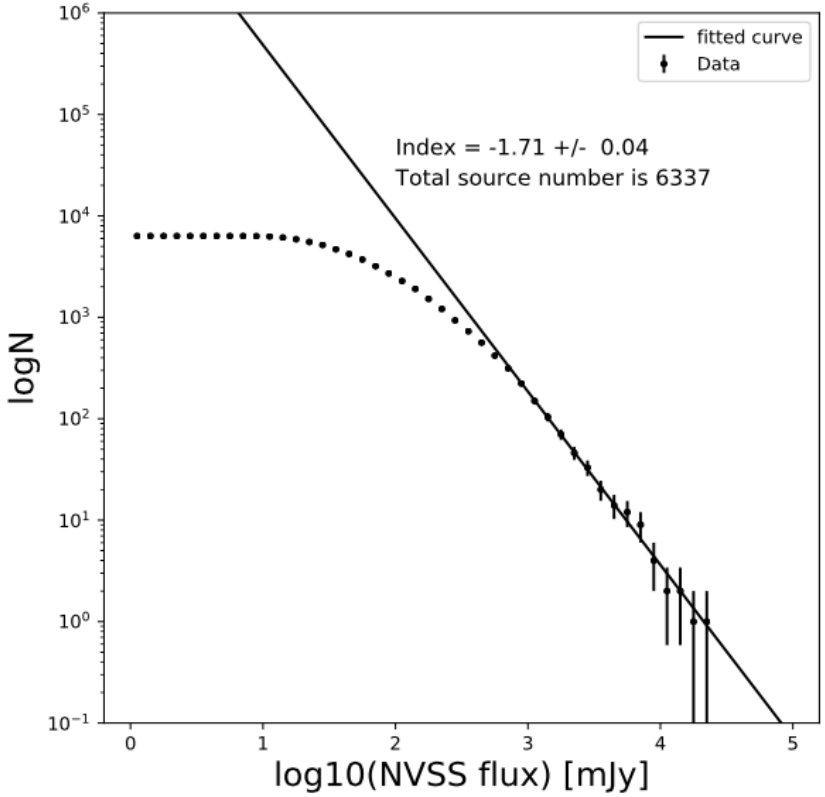


- Radio property seems different between the two populations
- Objects in the elliptical sequence show fainter radio fluxes, implying that they are BL Lacs
- They are candidates of Fermi-LAT unIDs and future TeV sources

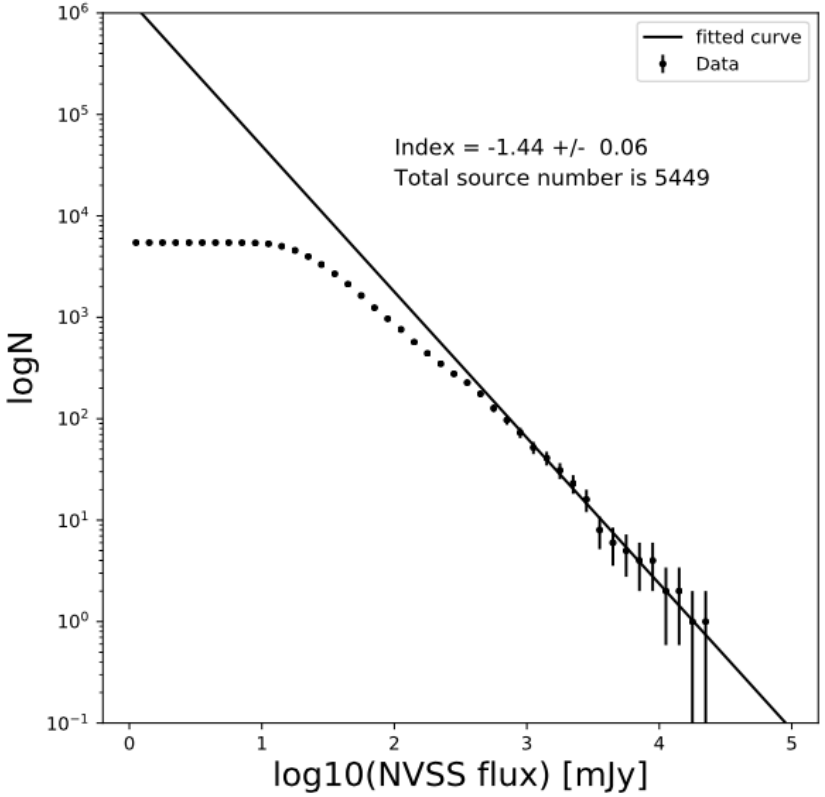


Log N-logS distributions

Quasar-sequence



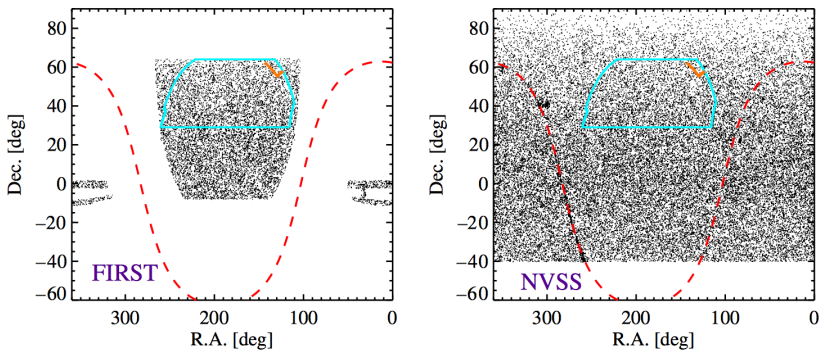
Elliptical-sequence



- Power-law index of logN-logS distribution for the Quasar sequence objects is 1.71+/-0.04, suggesting strong evolution
- In contrast, elliptical sequence show significantly flat index of 1.44+/-0.06

Summary

- We are making blazar candidate catalog using TGSS, NVSS and PS1 optical data
- We detected two distinct branches in the g vs g-r color-magnitude diagram, namely “elliptical-sequence” and “quasar-sequence”
- Objects in the “elliptical-sequence” indicate systematically lower radio fluxes compared to those in the “quasar-sequence”, possibly indicating that low-power BL Lac objects (like extreme HBLs) are buried in the elliptical sequence
- Such objects would be good CTA candidates
- We are now investigating a fraction of contaminants by radio galaxies by using FIRST radio images (which only covers ~20-30% of the BROS region though)



Kimball+08