ニュートリノフォローアップやTeVサーベイに向けた TGSS, NVSS, PS1を用いた 新しいブレーザー候補カタログ BROS: Blazar Radio and Optical Survey

田中康之（広島大学宇宙科学センター）
内海洋輔、井上芳幸 (ISAS/JAXA)、太田耕司(京大)

Outline

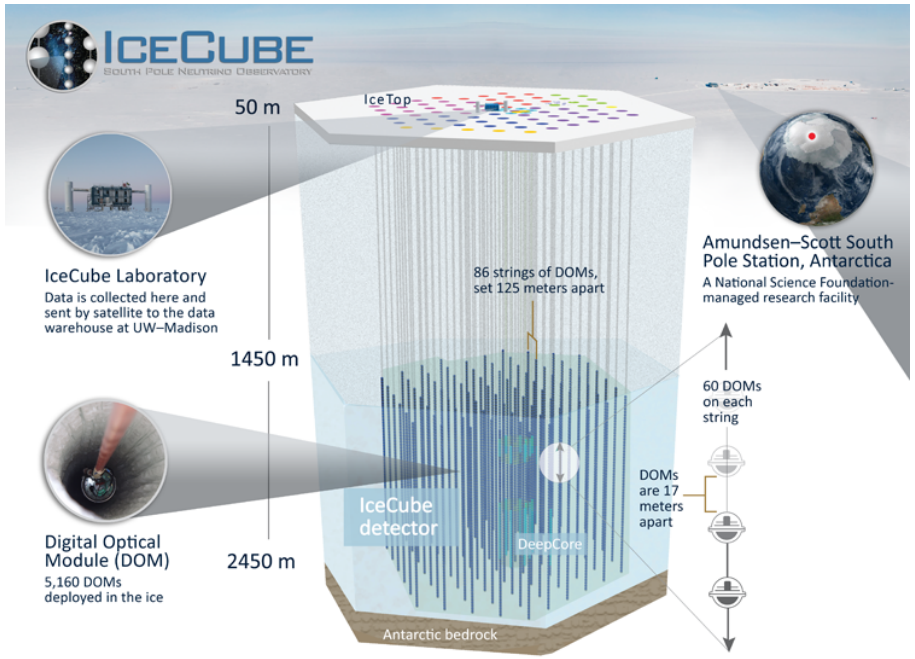
1. 本研究の動機 (IceCubeニュートリノフォローアップや TeVサーベイに向けて)

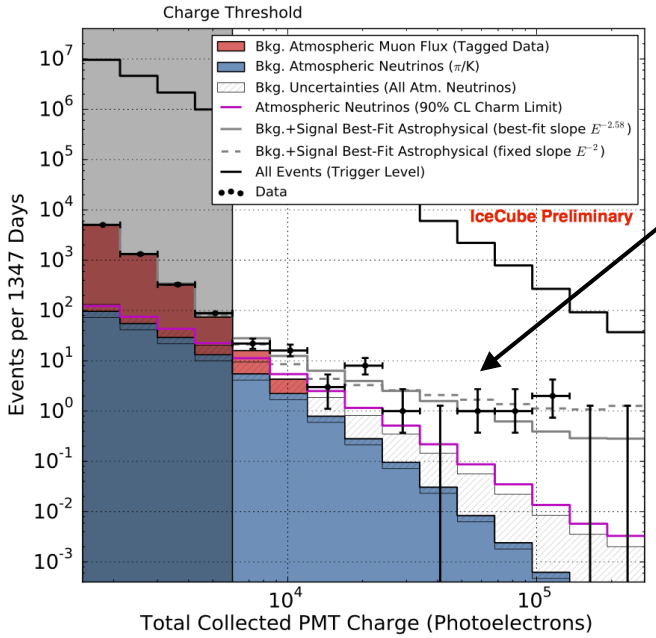
2. 先代のCRATESカタログ (Healey et al. 2007)

3. TGSS, NVSS, PS1データによる新しいブレーザー候補カタログ BROS

4. Summary

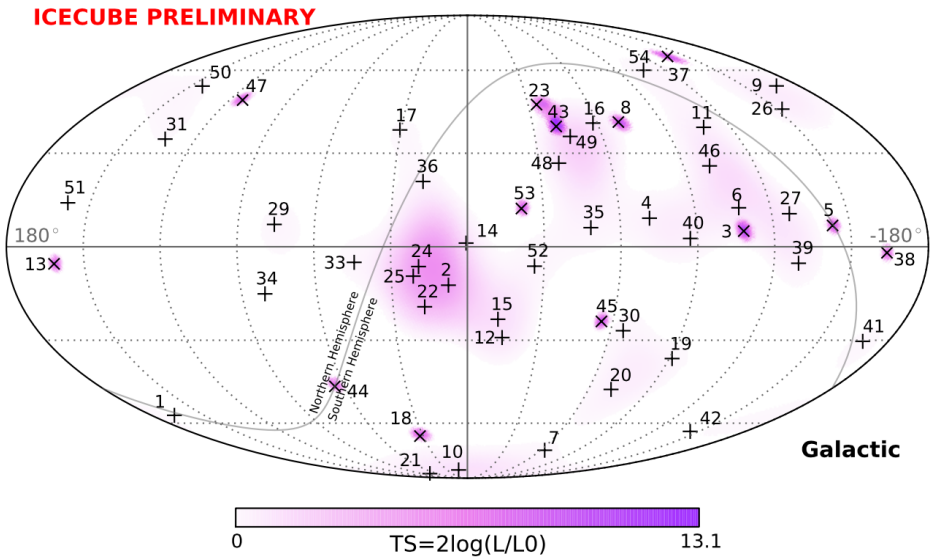
IceCube sub-PeV~PeV neutrinos





Excess at E>~100 TeV

Isotropic arrival direction and no clustering at e.g., Galactic Plane and nearby radio galaxies



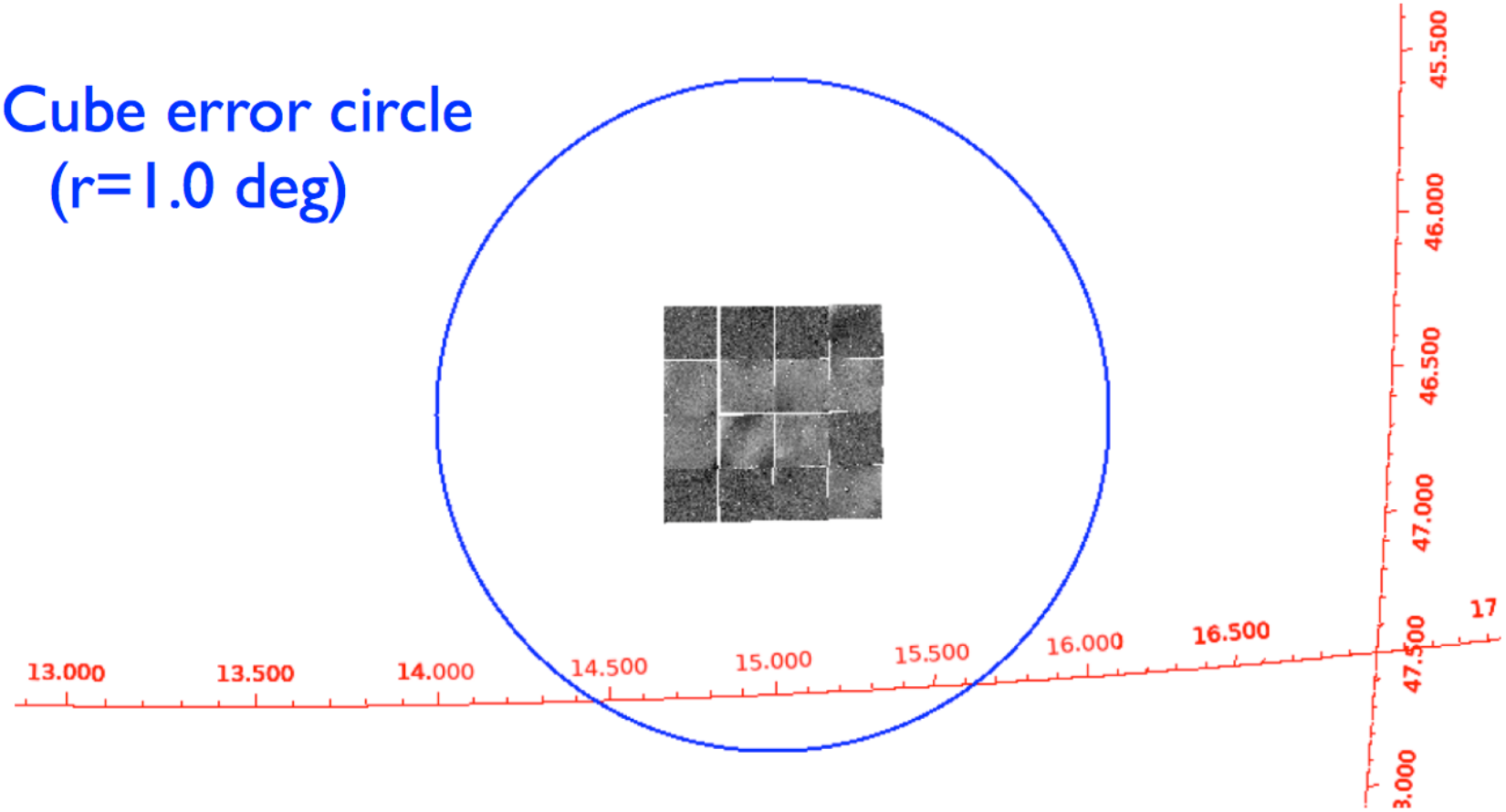
Origin is GRB? blazar? SN?

Kanata/HONIR ToO observation for IceCube-161210

- IceCube-161210
- 2016 December 10, UT 20:06:40.31
- RA=46.58, Dec=14.98, error circle radius=1 degree (50% C.L., systematic error included)
- 1.5m Kanata telescope located at Higashi-Hiroshima
- J and R-band simultaneous imaging
- 60 s (J) and 75 s (R) exposure in 1 frame
- 5-dithtering
- HONIR FoV: 10'x10'
- Central region of the large error circle was observed by 4x4 tiling observation (2hours for 16 pointings)

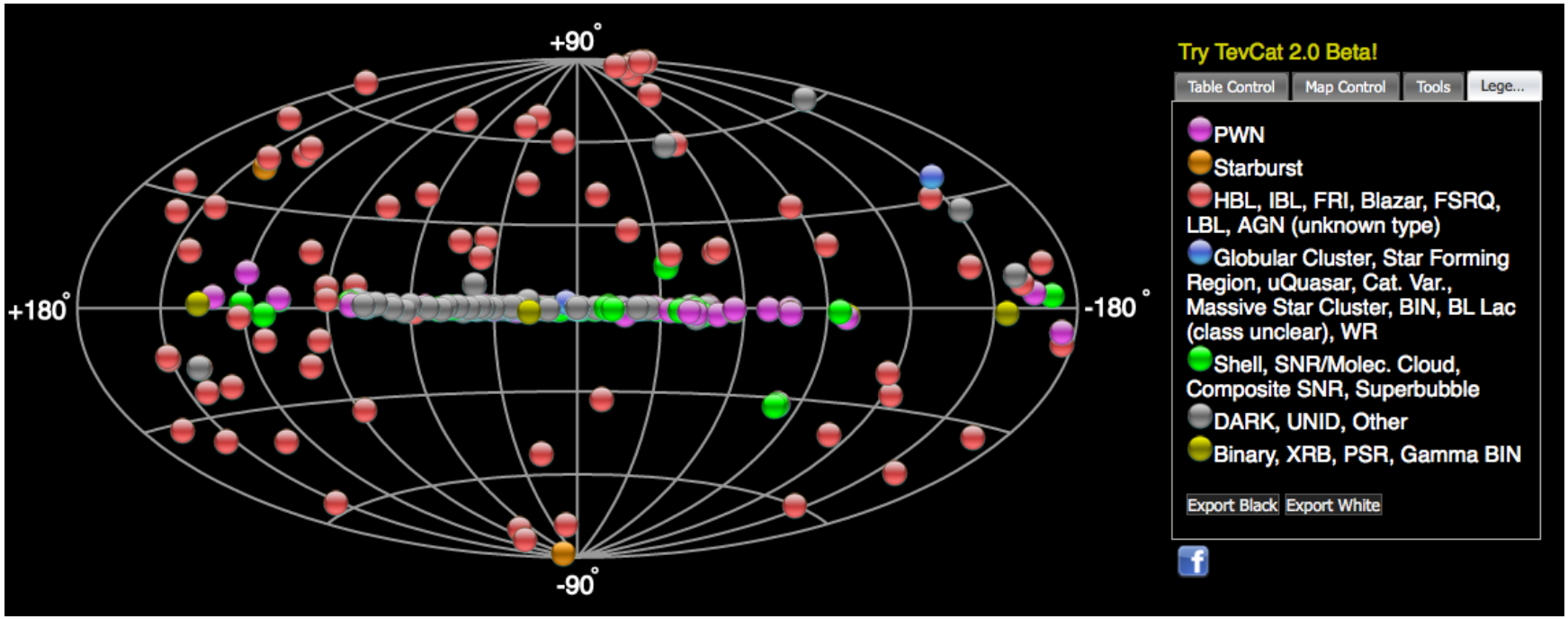
J-band tiling observation

IceCube error circle
(r=1.0 deg)



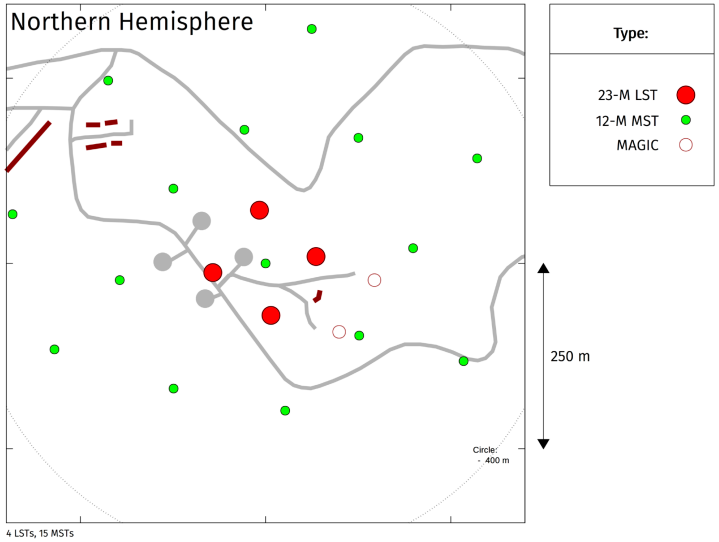
- As a reference frame, we used 2MASS images (2 Micron All Sky survey) and produced subtracted image
- Check the transients by eye
- No bright transient in the image, 5 sigma limiting magnitude J=18.8 (Mori et al., GCN20263)
- R-band analysis is still ongoing. (Subtraction of Pan-STARRS images is not going well)

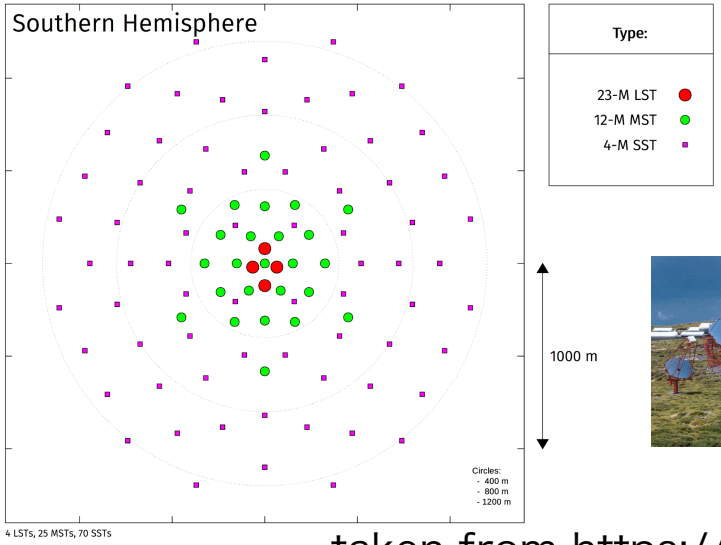
TeV gamma-ray sky



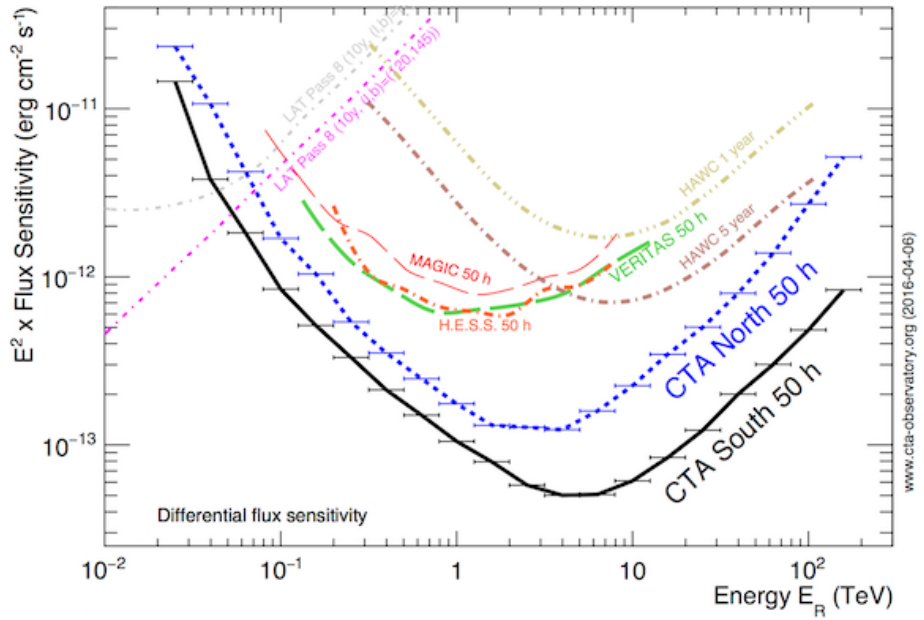
- Only ~100 TeV sources are detected so far
- at |b|>10 deg, most sources are blazars
- In the Galactic Plane, PWN and SNRs are dominant sources
- ~60 TeV are unIDs (mostly in the Galactic Plane)

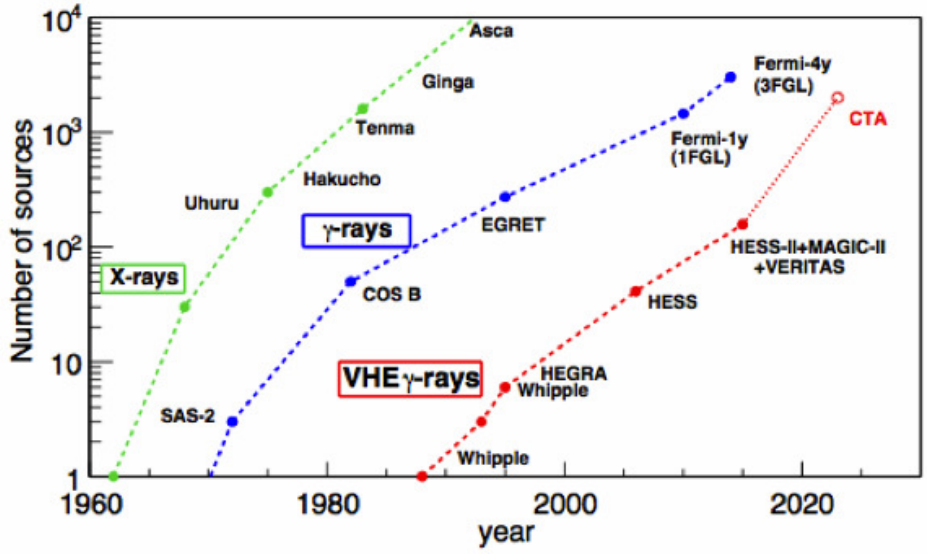
Cherenkov Telescope Array (CTA) in Pa Larma (Spain) and Paranal (Chile)



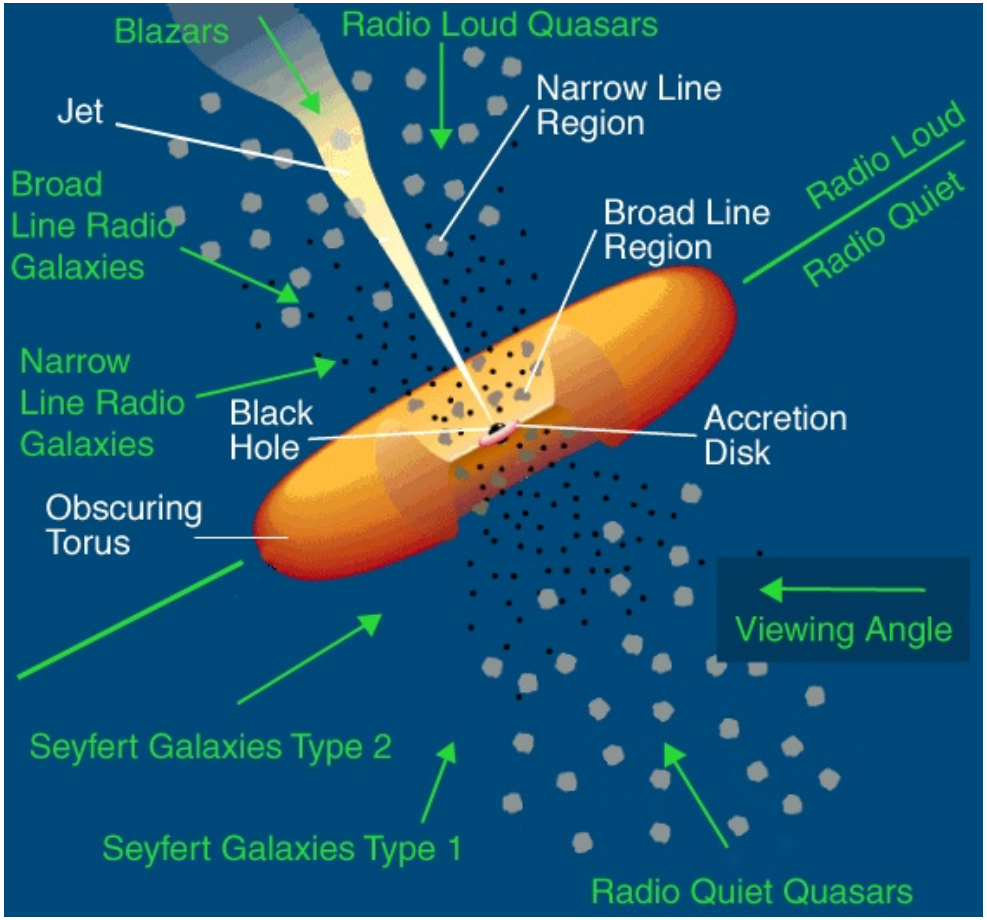


taken from https://www.cta-observatory.org



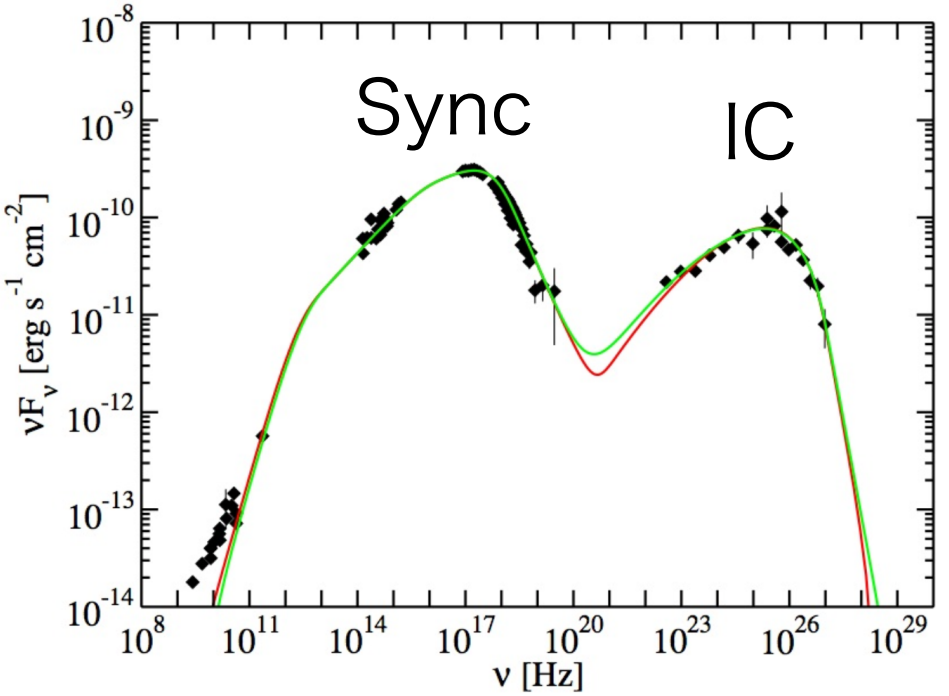


Jetted AGNs:
Radio galaxies and blazars



Radio-loud AGNs are about 10%

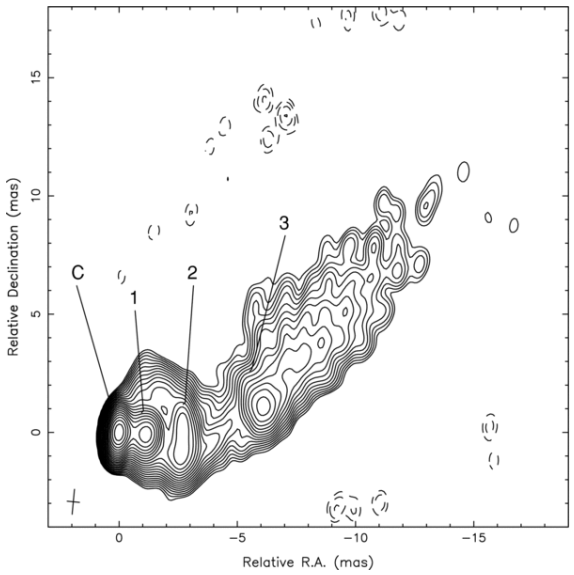
- ✓ Radio galaxies: Large viewing angle
- ✓ Blazars: Small viewing angle

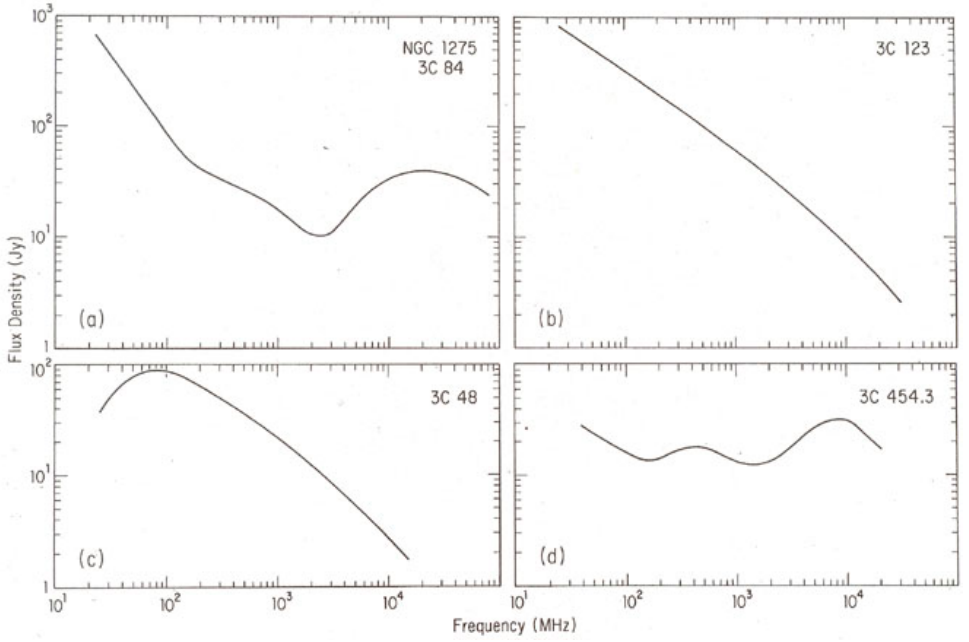


Mrk 421 (Abdo+11)

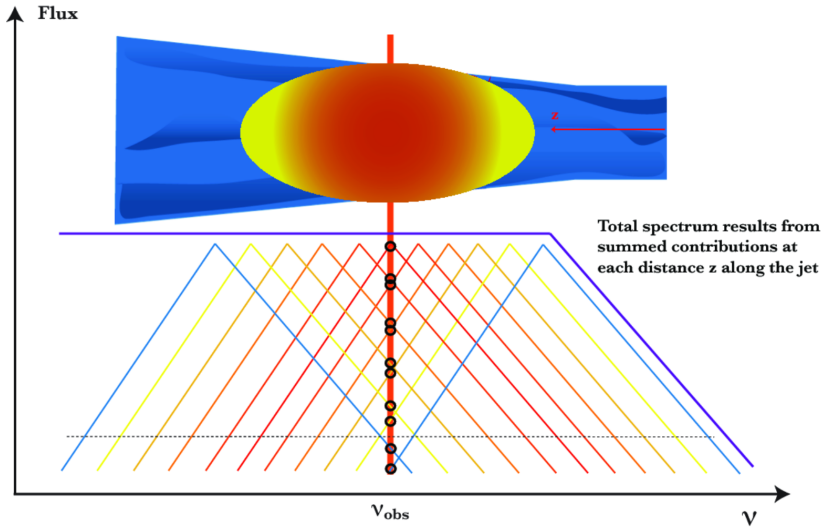
Blazars in radio band

VLBA image





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

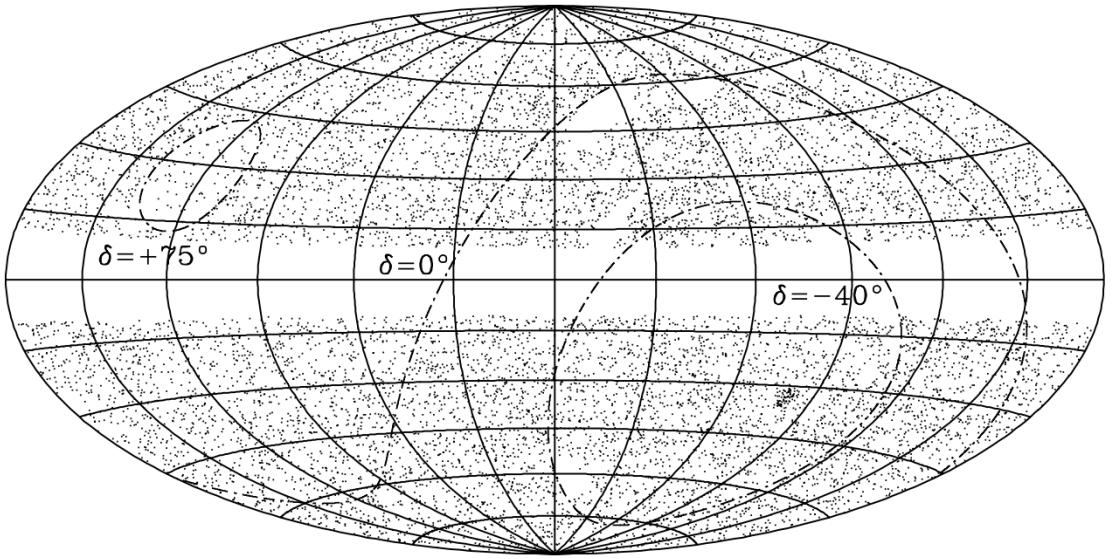


CRATES blazar-candidate catalog (Healey et al. 2007)

- Flat radio sources at 1.4 GHz, 4.8 GHz and 8.4 GHz using NVSS, GB6, and VLA archives

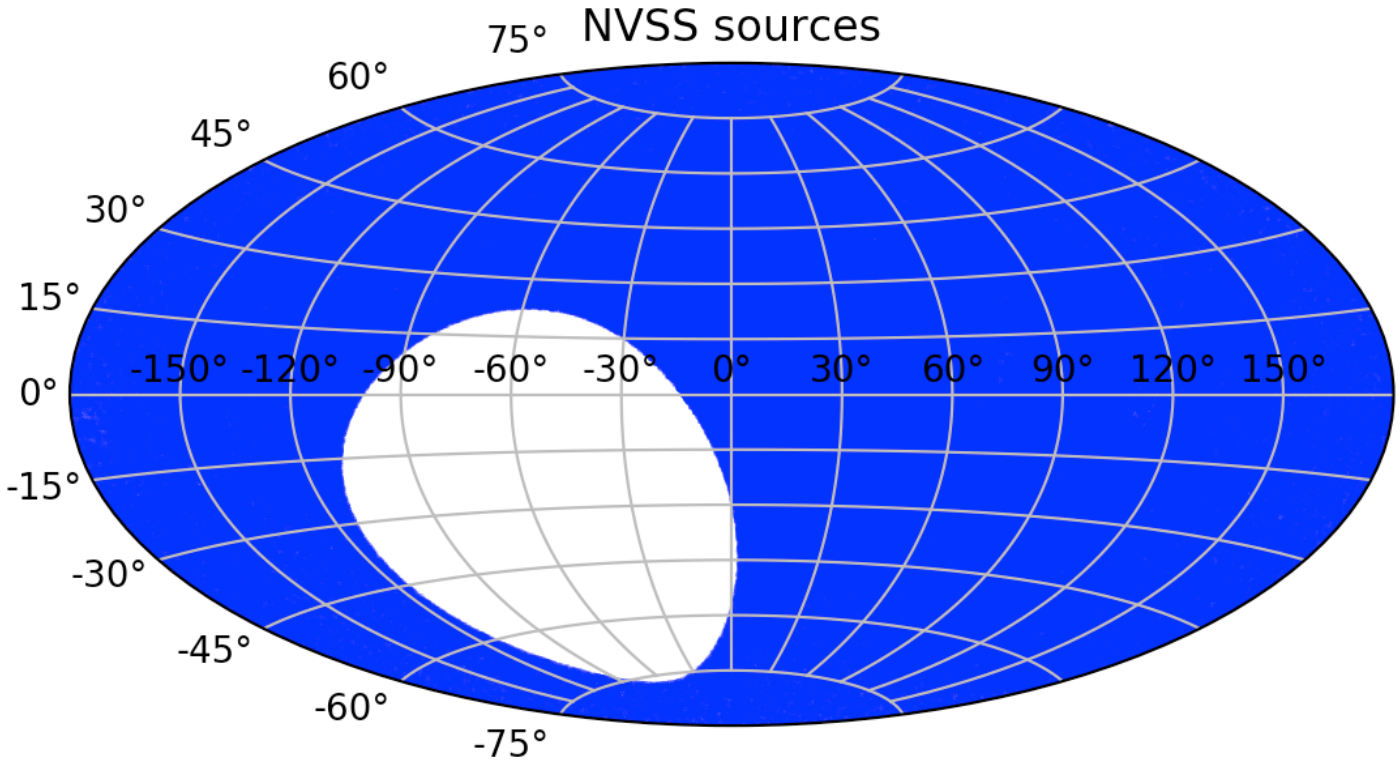
- 11131 sources with $F_{4.8GHz}$ > 65 mJy and located at |b|>10 deg

- It was useful to identify Fermi MeV/GeV blazars and unIDs at high Galactic latitude



NVSS (NRAO VLA Sky Survey)

- 1.4 GHz survey with VLA (Condon et al. 1998)
- Region of δ>-40 deg with the sensitivity of $F_{1.4GHz} > 2.5$ mJy
- 2 million sources



TGSS

- GMRT 150 MHz survey at δ>-53 deg (Intema et al. 2016)
- RMS noise: 3.5 mJy/beam
- 25” resolution
- 0.62 million sources

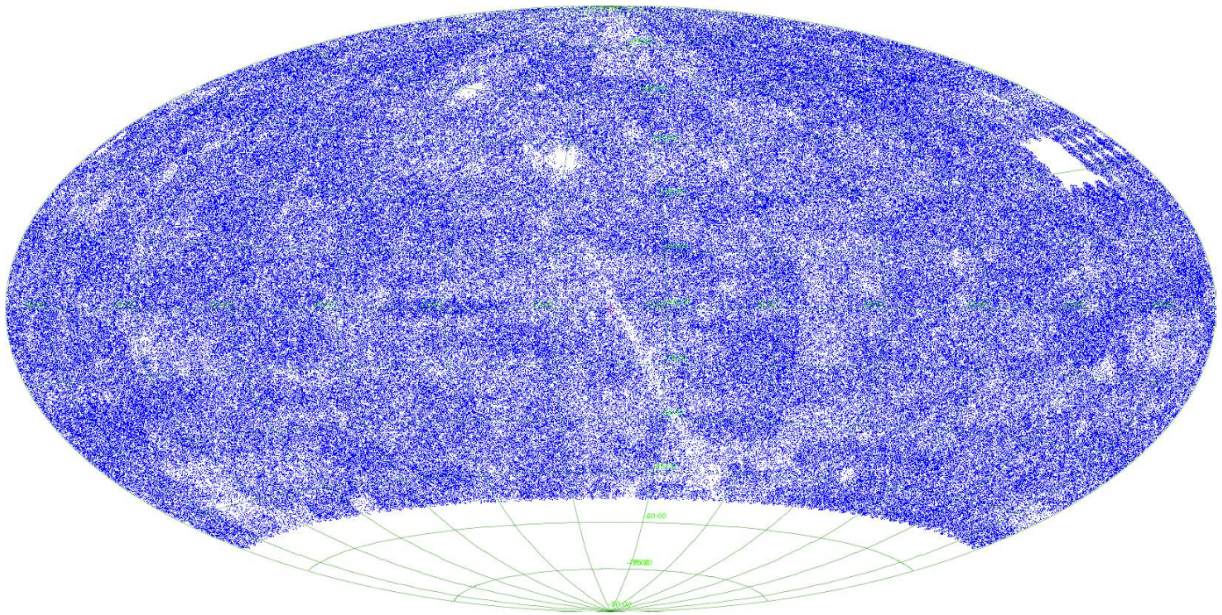
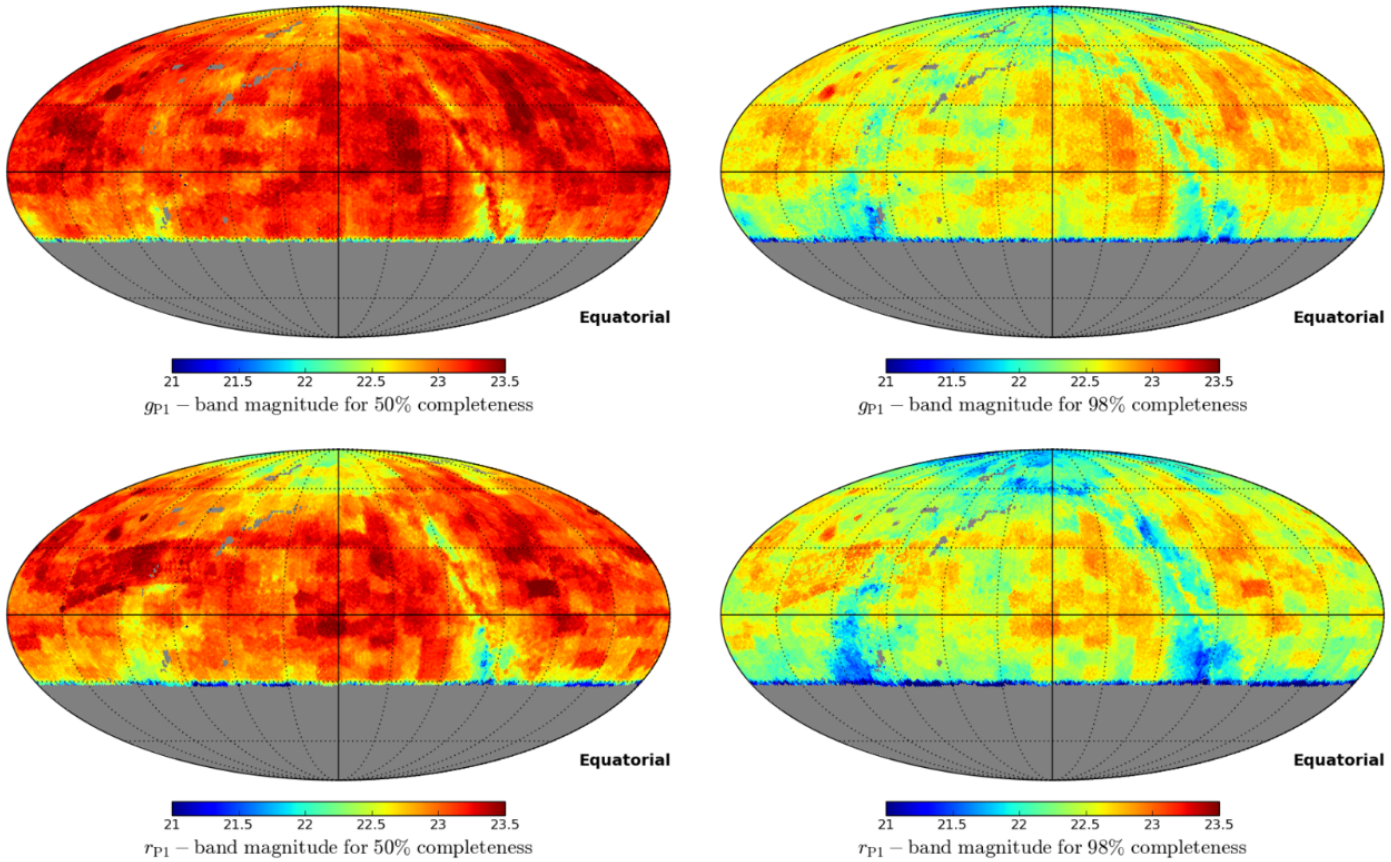


Fig. B.2. As Figure B.1, but now marking the spatial distribution of the 623,604 extracted sources in this data release. The extracted source density is correlated with the background RMS noise distribution as depicted in Figure 8.

By cross-matching with NVSS and TGSS,
flat-spectrum radio sources are selected

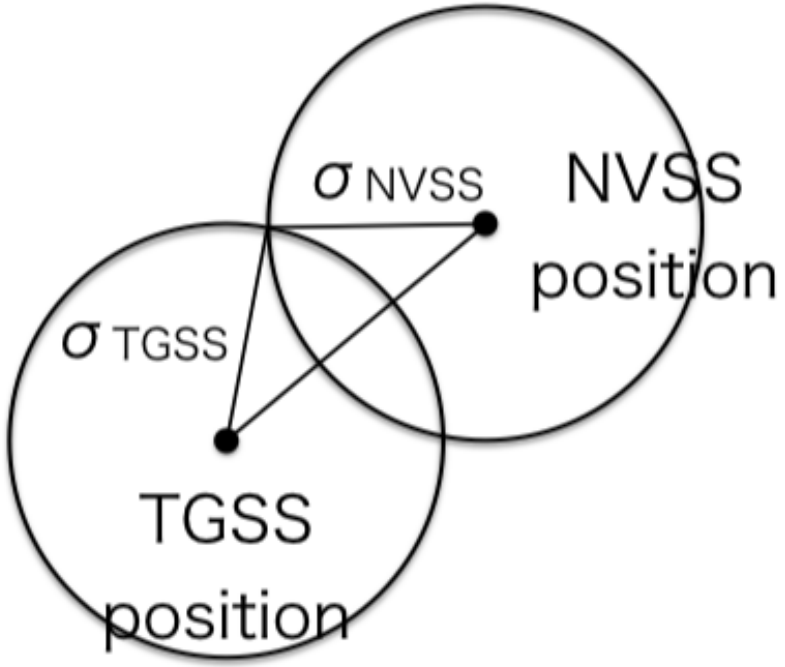
Pan-STARRS1

- 3pi sky survey with grizy limiting magnitudes of 23.3, 23.2, 23.1, 22.3, 21.4, respectively



Chambers et al. 2017

Cross-matching method

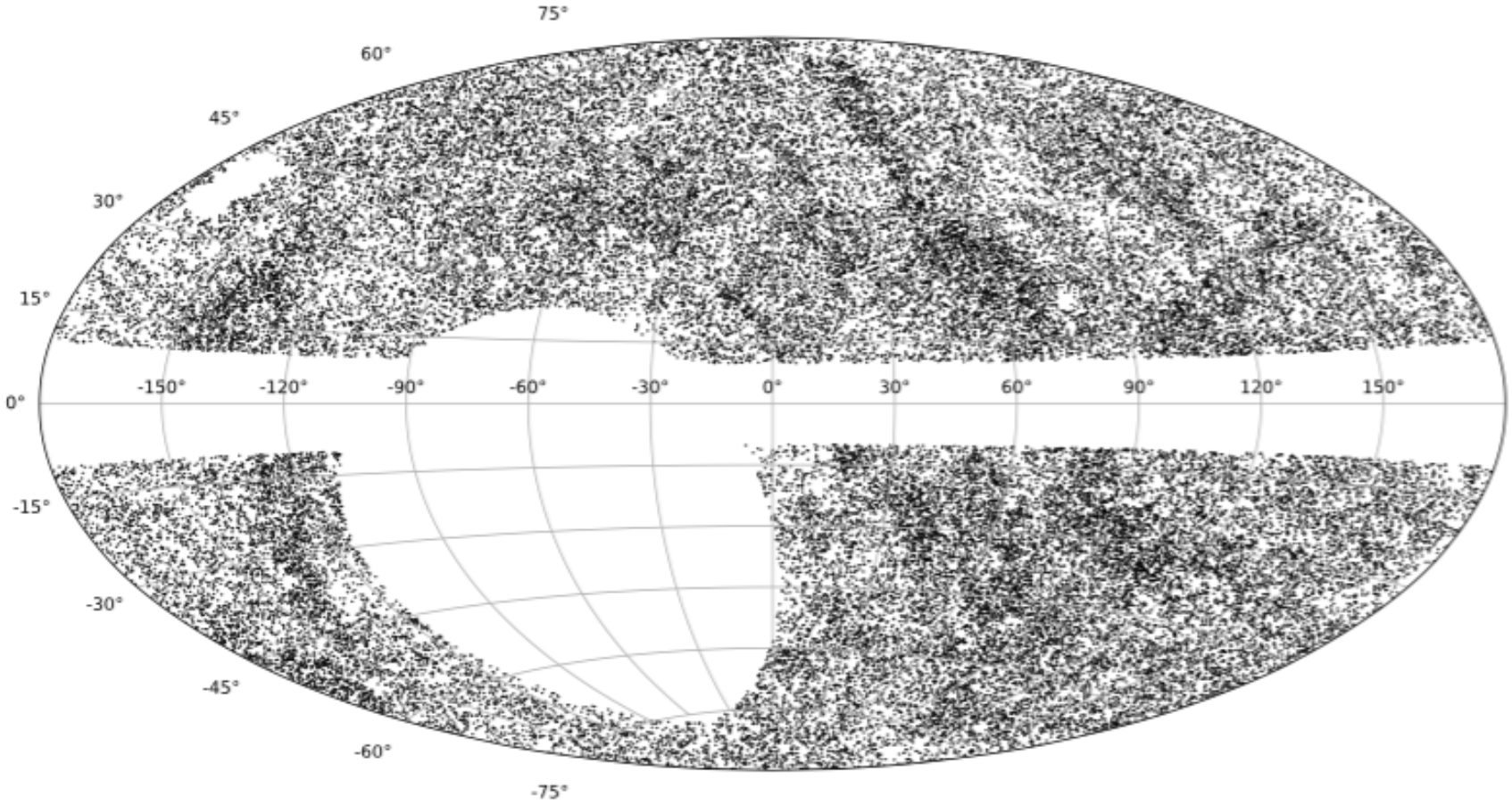


- Typical positional uncertainties
  - ✓ NVSS: 1-7 arcsec
  - ✓ TGSS: 2-5 arcsec

PS1 sources located with the smallest
angular separations within the TGSS 1sigma radius
were identified asoptical counterparts of BROS sources

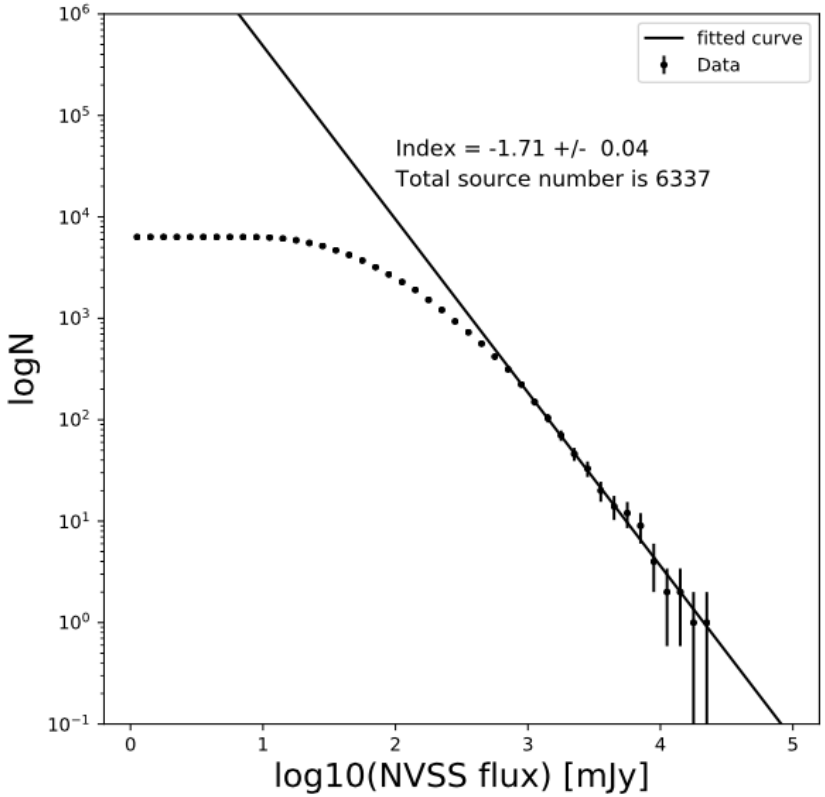
Sky distribution

- 56314 flat-spectrum radio sources (i.e., blazar-candidates) located at |b|>10 deg and δ>-40 deg are listed

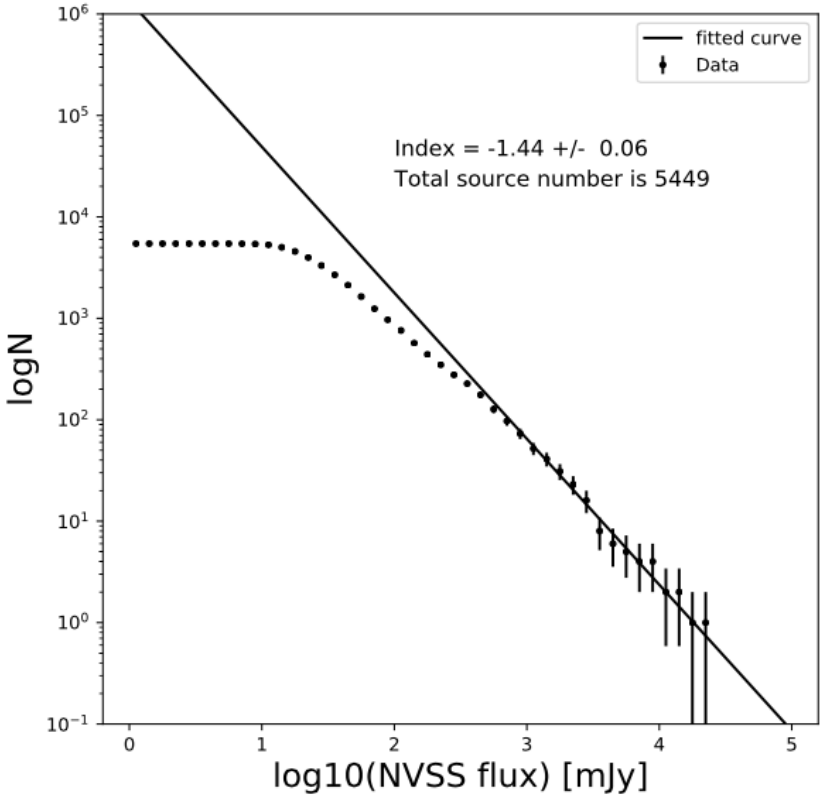


Log N-logS

Quasar-like

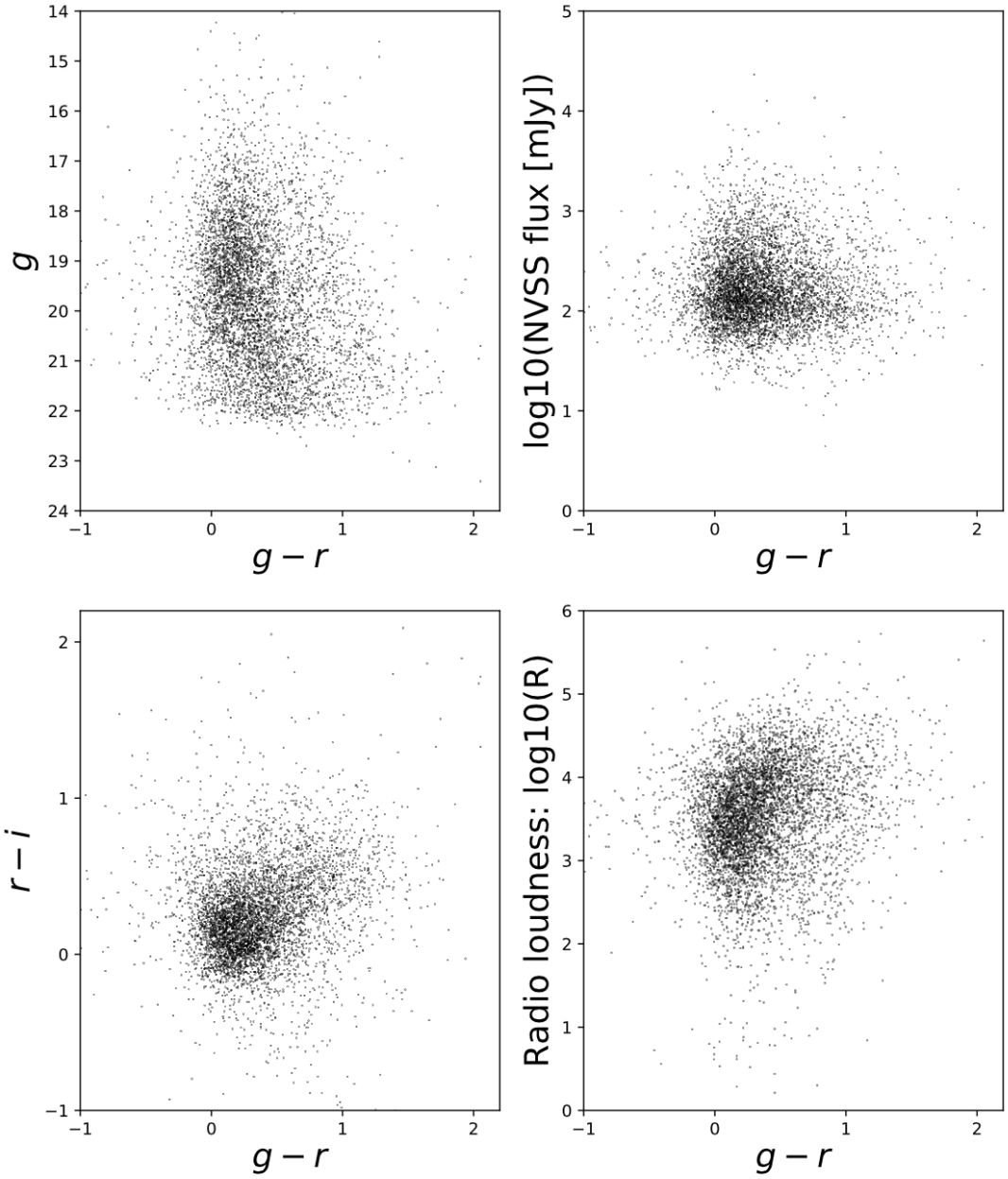


Elliptical-galaxy-like



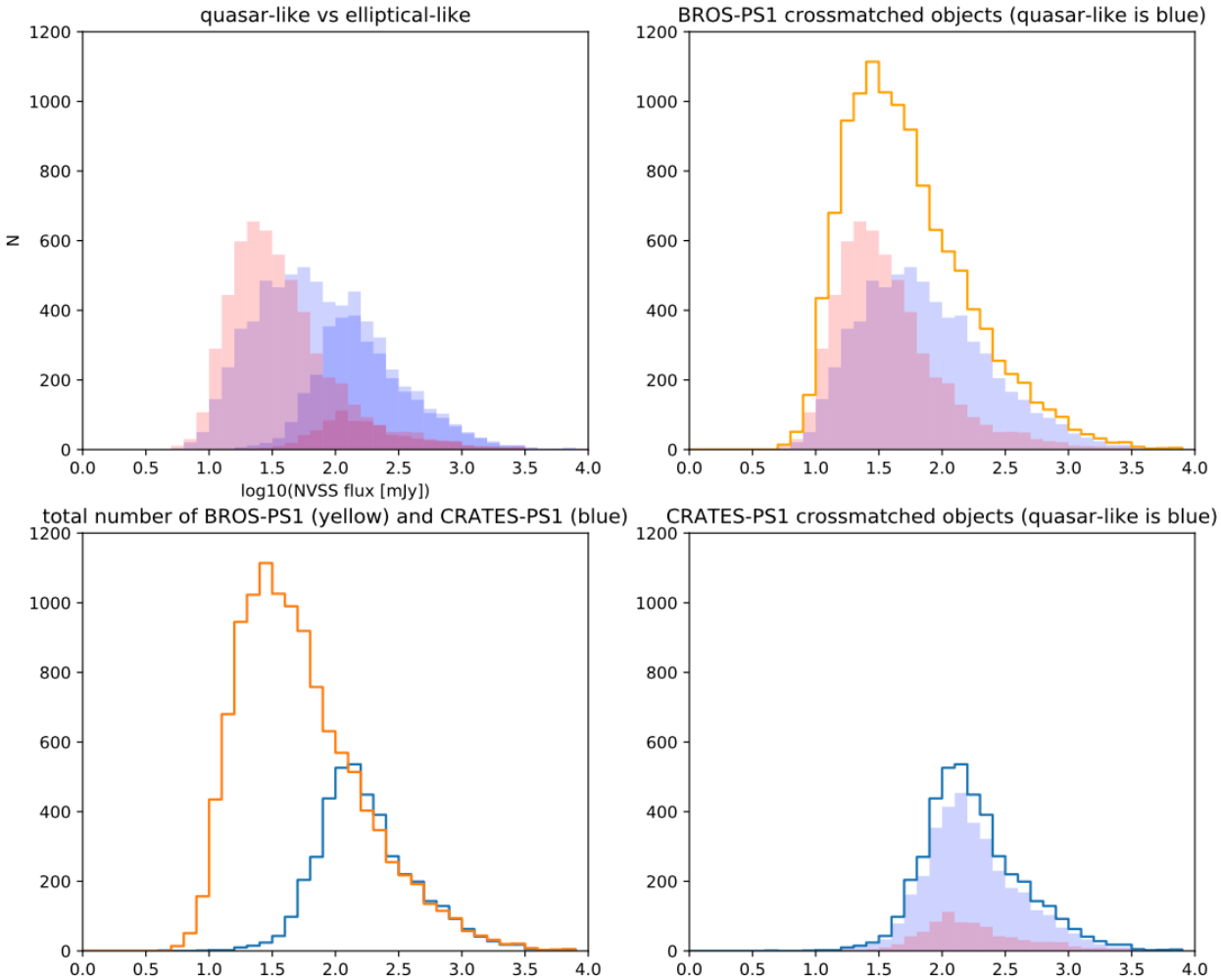
- 1.71+/-0.04, suggesting that quasars are abundant at high-redshift
- 1.44+/-0.06, suggesting that sources are dominated by nearby objects

CRATES-PS1



- Elliptical-like populations are not present, possibly due to high radio flux threshold ($F_{4.8GHz}$ > 65 mJy)

Comparison between CRATES and BROS sources



- It is clear that CRATES sources are brighter population of BROS sources

Summary

- We have completed a new blazar-candidate catalog, BROS, by selecting flat-spectrum radio sources from NVSS and TGSS catalogs
- Their optical counterparts are identified from PS1 data
- We clearly detected two populations: “Quasar-like” and “Elliptical-galaxy-like”, the latter of which are not seen in the CRATES-PS1 search
- The latter population is consistent with elliptical galaxy at z<~0.3
- Power-law index of logN-logS distribution supports this hypothesis
- Our BROS catalog is useful for IceCube neutrino follow-up and future TeV survey at high galactic latitude
- By using Subaru/HSC and photo-z, we will construct luminosity function of BL Lac objects and confirm their negative evolution (if possible)