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Compact steep-spectrum sources in a large statistically complete VLBA survey of the North Polar Cap

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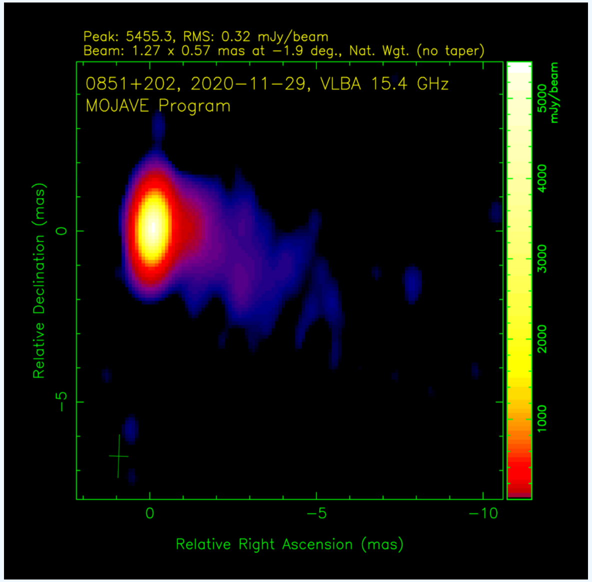
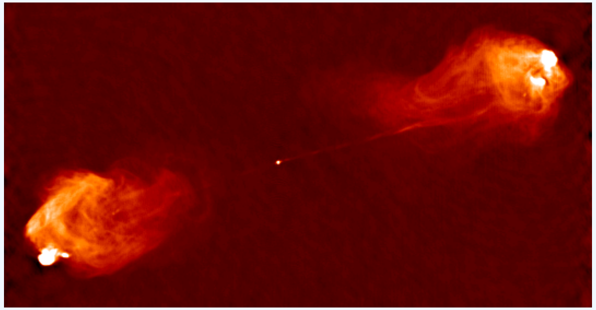
Motivation

- Flat-spectrum sources are thought to be more compact than steep-spectrum sources
- Most of large VLBI surveys observed only flat-spectrum sources => they miss CSS sources
- Need for VLBI studies of large samples of steep-spectrum sources
- We observed an unbiased total-flux-density limited sample of almost 500 sources with the VLBA and analyzed the relations between the parsec-scale structure and the total broadband radio spectra
- We determined the fraction of compact objects among flat-spectrum and steep-spectrum sources
- We compared parsec-scale properties of compact sources with flat and steep spectra





VLBA North Polar Cap Survey (NPCS)

- Sample selection criteria:
  - Total flux density $S_{1.4GHz} \geq 0.2$ Jy (NVSS catalog)
  - Declination > +75°
- 482 sources in total
- VLBA observations (code BK130):
  - 2.3 GHz & 8.6 GHz simultaneously
  - 8-minutes snapshot for each source
  - 3 x 24 hours in total (14, 16, and 23 February 2006)

Single-dish broadband radio spectra

- Broadband quasi-simultaneous 1-22 GHz spectra obtained at RATAN-600 (Mingaliev et al. 2007) for all but 21 sources
- Non-simultaneous spectra from the CATS database for the rest https://www.sao.ru/cats/
- Multi-epoch spectra for ~1/3 of the sample, collected from our RATAN-600 monitoring program and from the literature

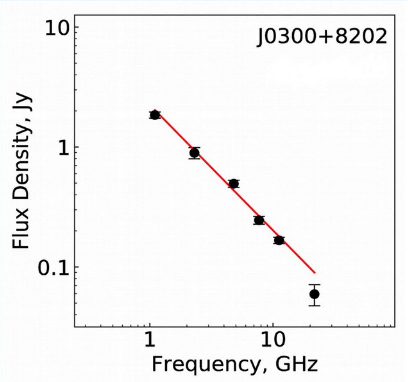
Types of spectra

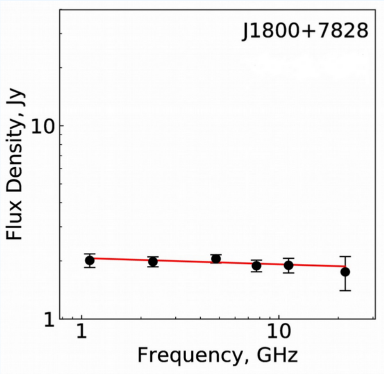
Flux density $S \sim \nu^{\alpha}$, α – spectral index

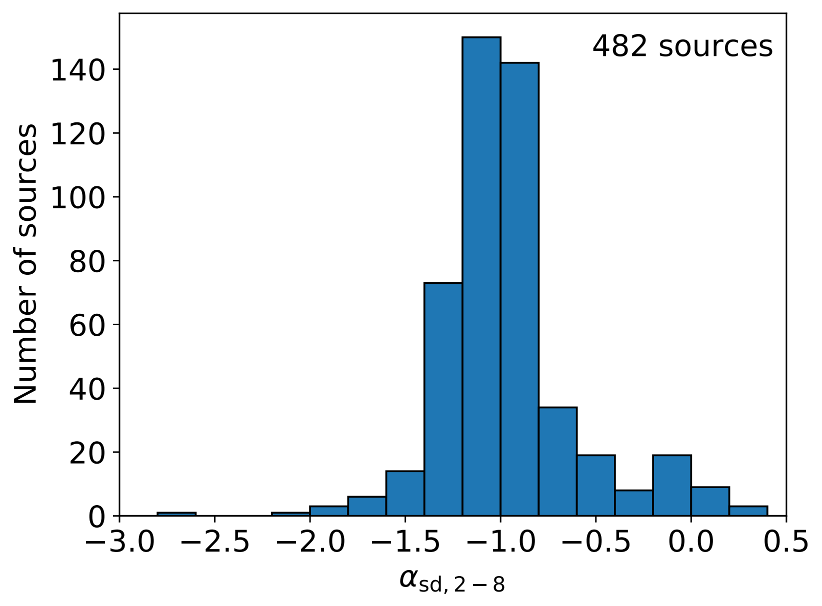
We classify the spectra as follows:

- Flat – spectral index at 2-8 GHz
  $\alpha_{2\text{-}8} \geq -0.5$
- Steep – spectral index at 2-8 GHz
  $\alpha_{2\text{-}8} < -0.5$
- Peaked (GPS)

NPCS sample:
90% - steep-spectrum sources,
9% - flat-spectrum sources,
1% - GPS

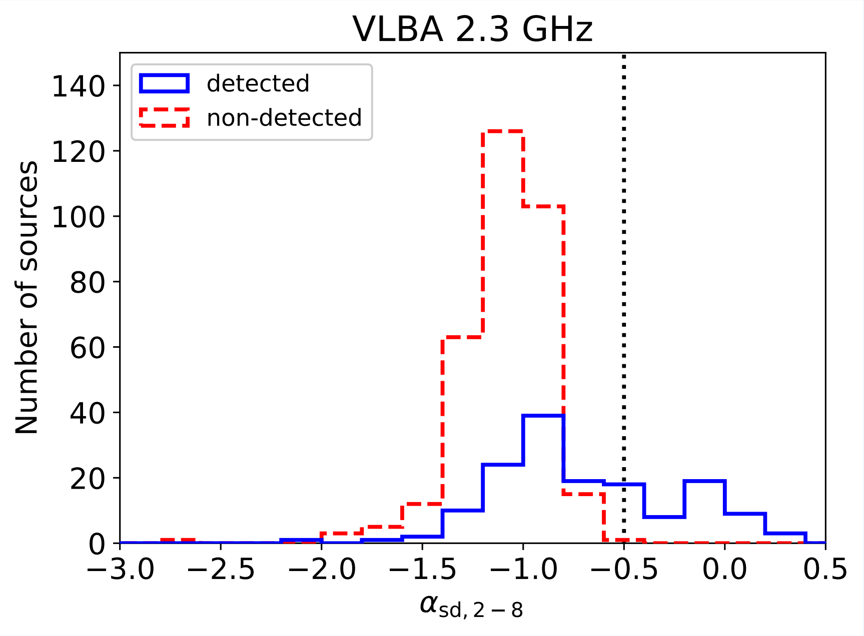


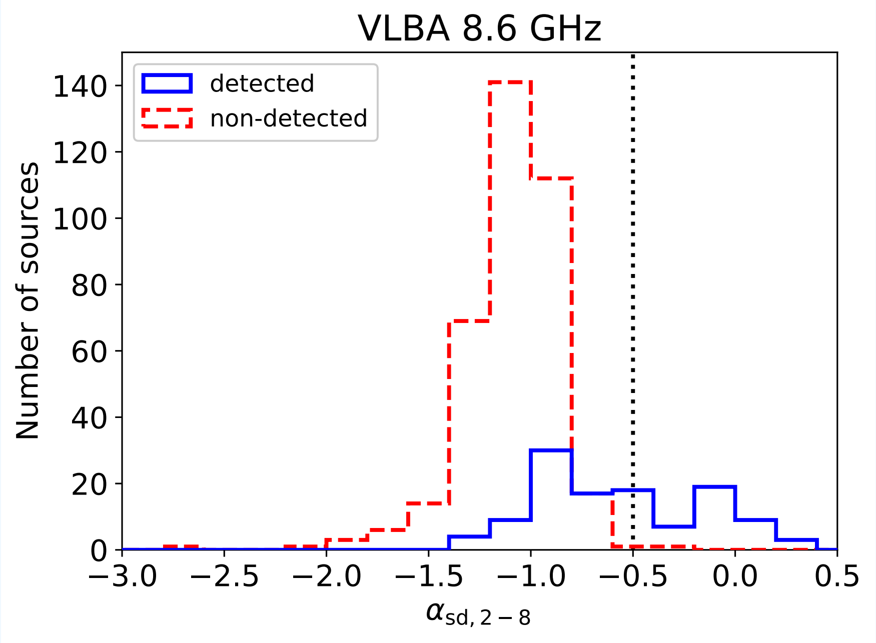




VLBA detections

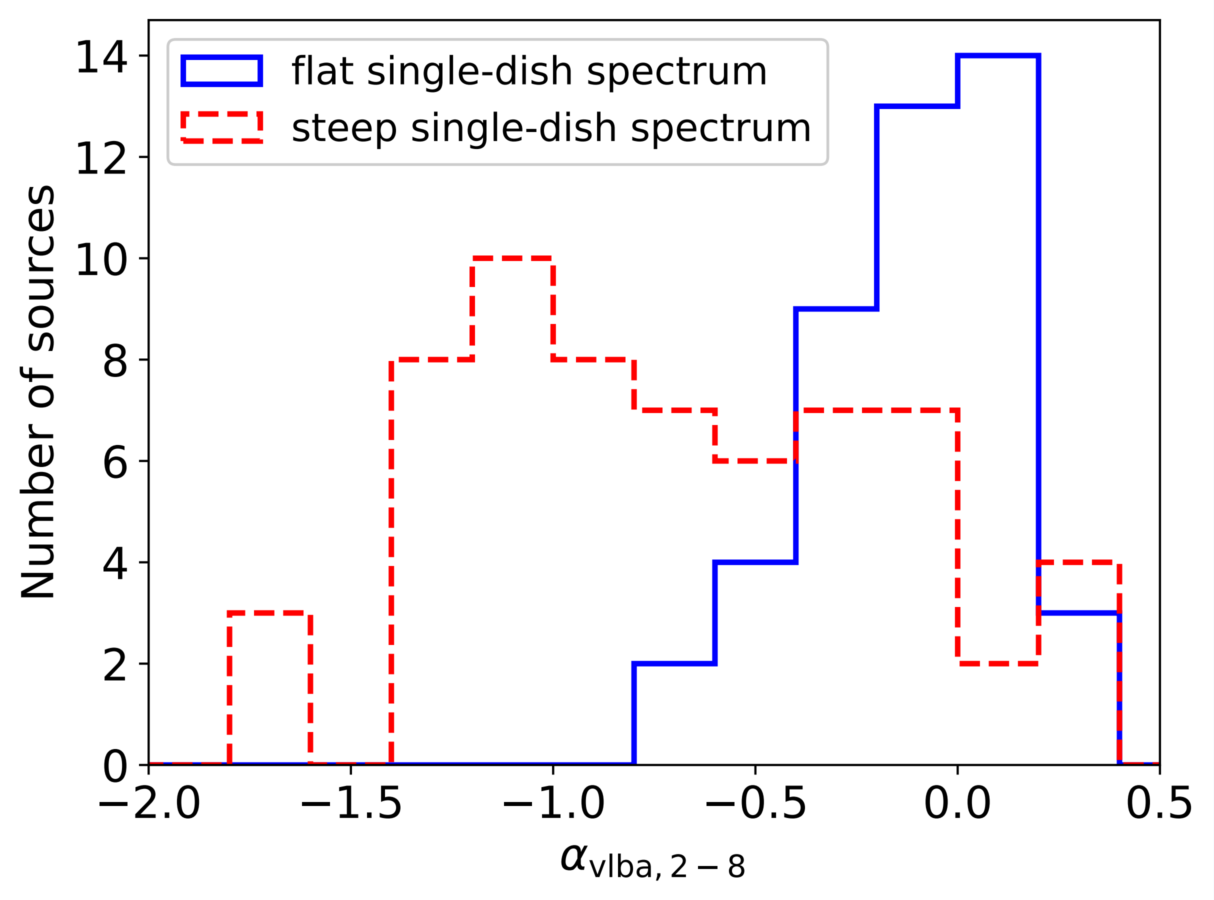
Flux density detection limit ~30 mJy
VLBA is sensible to angular scales <0.1″ at 2.3 GHz and <0.03″ at 8.6 GHz.





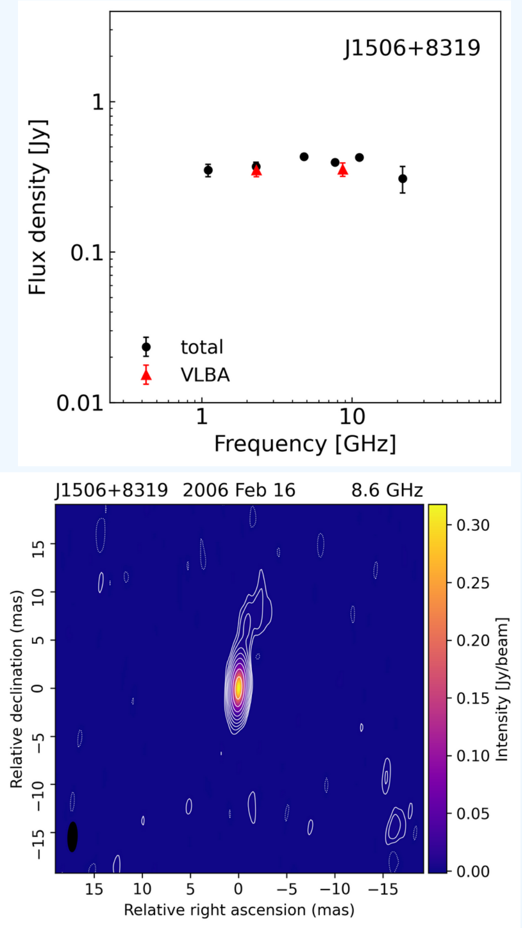
- Among 162 detected sources, **72% have a steep total (single-dish) spectrum**.
- Detection rate of steep-spectrum sources ≈25%
- All 5 GPS sources detected

VLBA spectral index

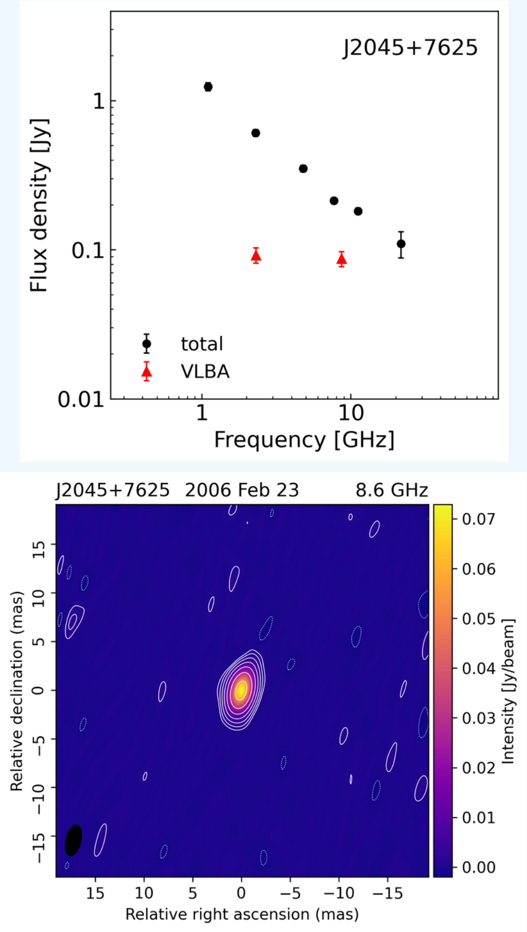


α_{vlba} – VLBA spectral index, calculated using total VLBA flux densities at 2.3 and 8.6 GHz

Flat VLBA spectrum sources

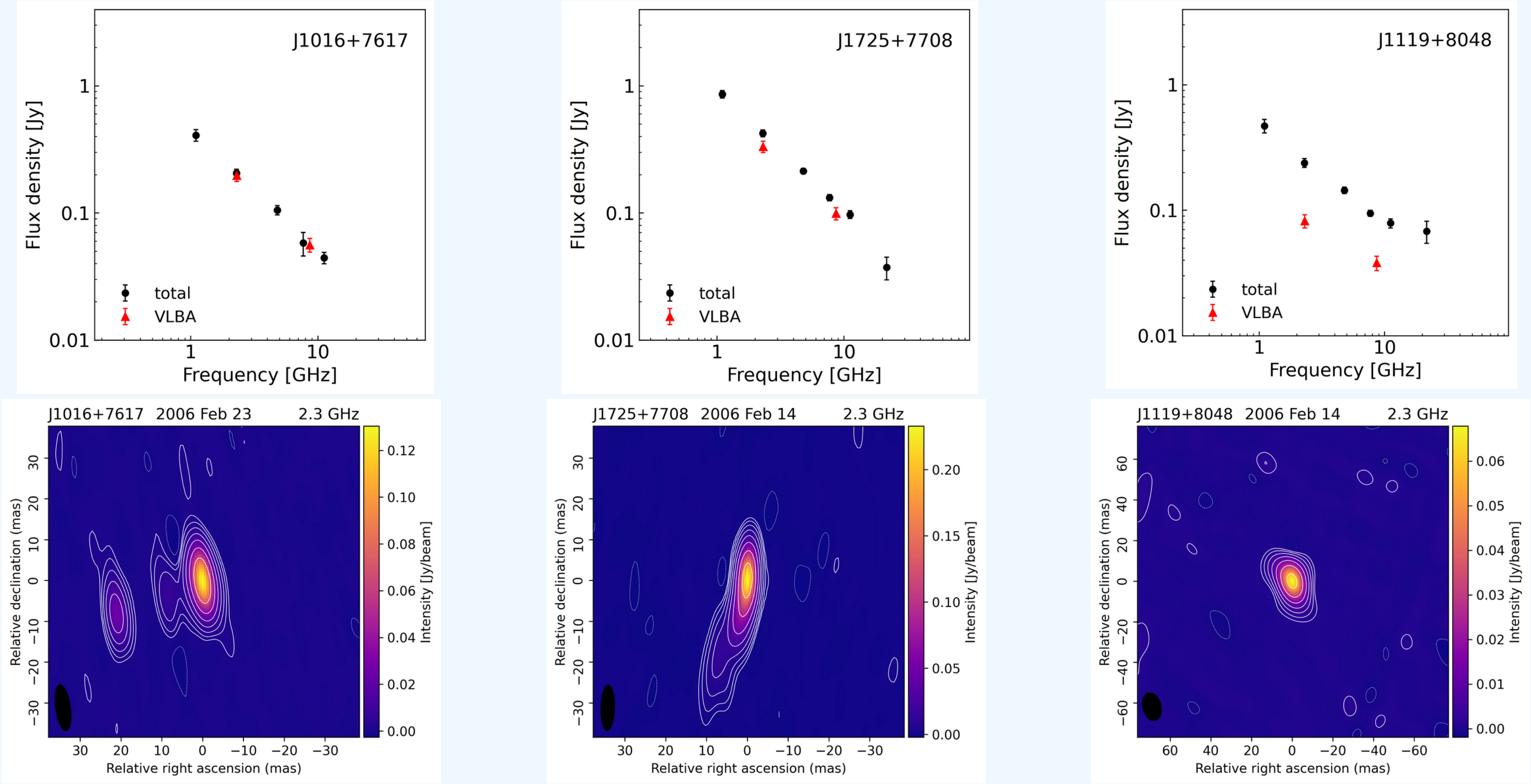


37 sources (8% of the sample)



30 sources (6% of the sample)

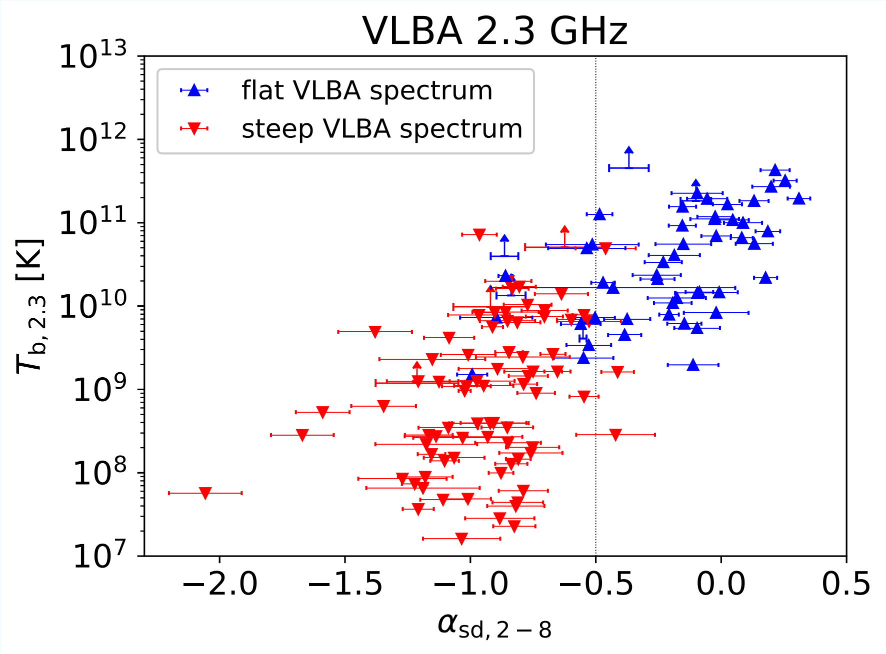
Steep VLBA spectrum sources

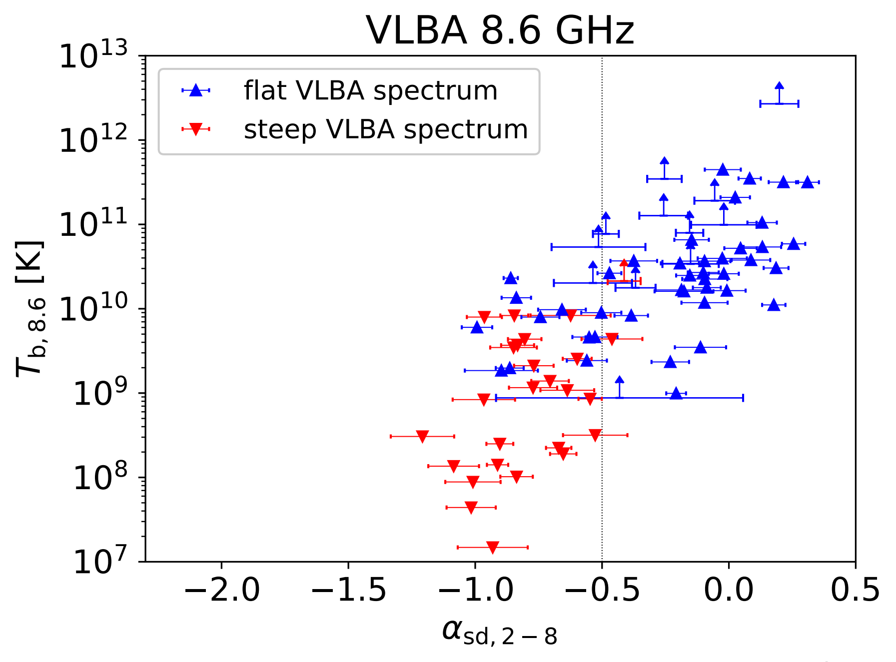


82 CSS candidates (17% of the sample)

Brightness temperature

We fitted models of 1 or 2 circular Gaussians, depending on source structure and data quality, to the visibilities, and obtained characteristic T_b and size of dominating features.





$\tau_{Kendall} = 0.51 \pm 0.06$, $p \approx 10^{-18}$

$\tau_{Kendall} = 0.52 \pm 0.07$, $p \approx 2*10^{-12}$

Average T_b of CSS candidates is 10-100 times lower than average T_b of the sources with flat VLBA spectra. Dominating features of CSS candidates are not jet cores, but outer jets or mini-lobes.

Summary

- We observed with VLBA a large, flux-density limited sample with no bias to flat-spectrum sources.
- The majority, or 72%, of the detected compact sources have a steep single-dish spectrum.
- We found 82 CSS candidates (17% of the sample), most of them are reported for the first time.
- Relatively low brightness temperature (10^7-10^{10} K) and practically no variability of CSS candidates indicates that their dominating features are not jet cores, but outer jets or mini-lobes.
- Details in *Popkov A. V. et al., 2021, Astronomical Journal, 161, 88* *https://arxiv.org/abs/2008.06803*