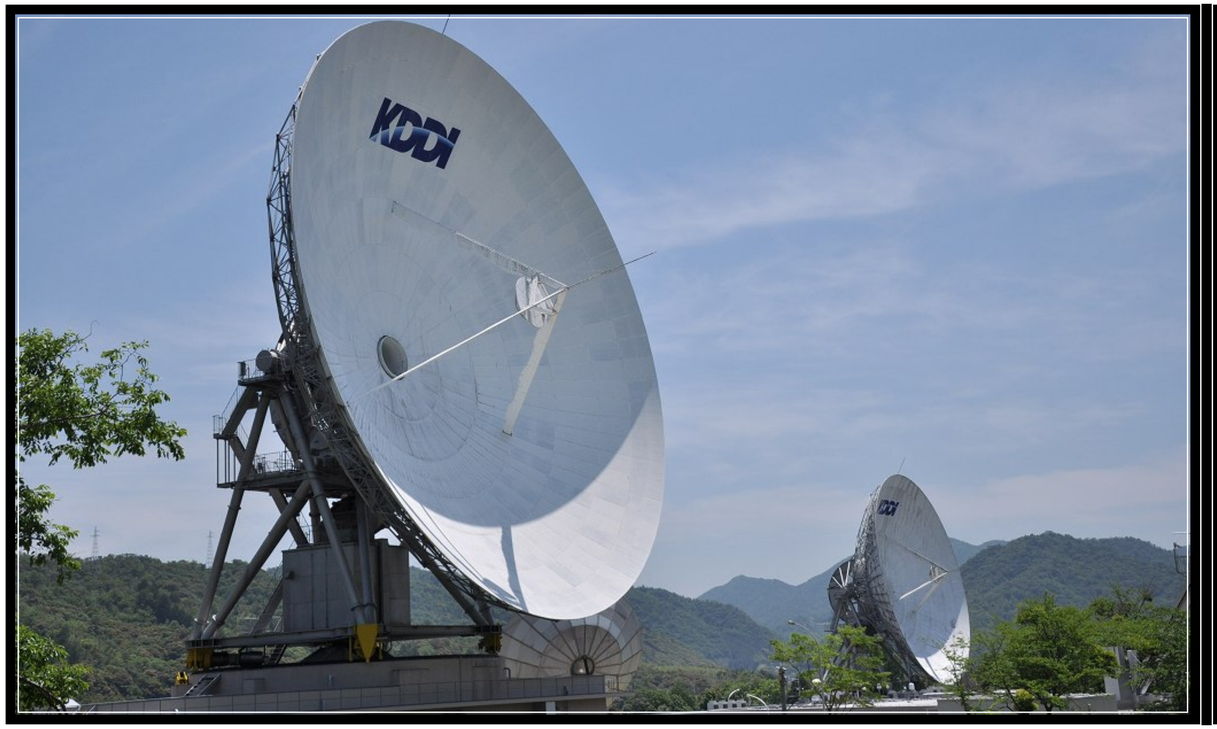
Redshift distribution of powerful AGN jets observed by JVN at z > 3.



Yosuke Furuya (Yamaguchi Univ.)

Collaborator: Hiroki Tsuruta, Kotaro Niinuma, and Kenta Fujisawa (Yamaguchi univ.)

The cosmological evolution of AGN jets

Observational feature of high-z AGN jets

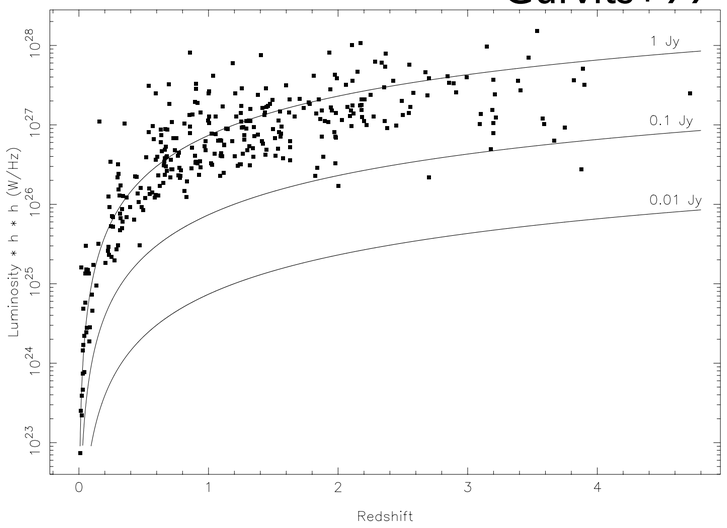
- Brighter than Low-z AGN jets (more than ×3)
- Compact radio structure (≤ a few arcsec)

→ **Doppler Beaming effect??**

[Prediction]

The detection ratio of blazar is mostly higher than that of other types at high-z by the beaming.

Gurvits+99



○ **<u>The cosmological evolution of space density of blazar</u>**

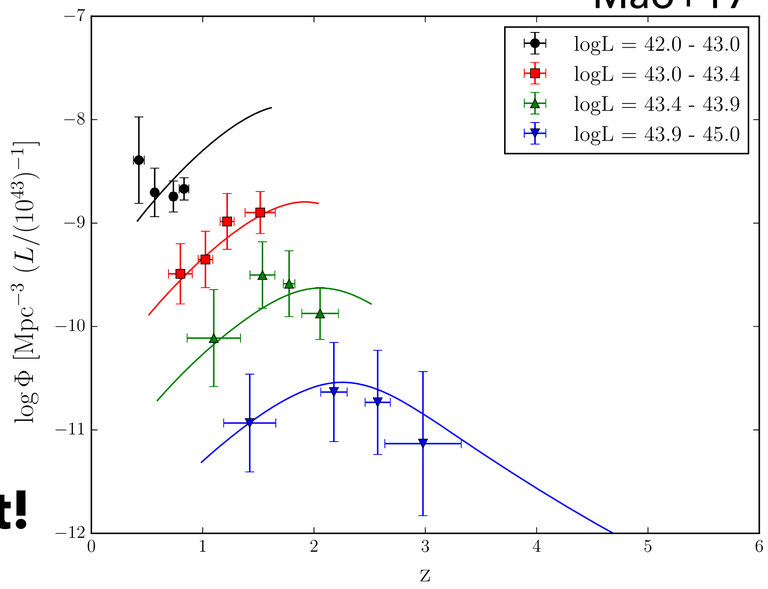
- **<u>LDDE (Luminosity-dependent density evolution)</u>**

  The cosmological evolution of FSRQs is depended on the luminosity. Brighter FSRQ grows at lowerredshift (Ueda+03)
- Maximum space density: z~2 (Mao+17)

▷ <u>If "Perfect" LDDE model is estimated…</u>

- **The number of the FSRQ can be estimated at each redshift!**

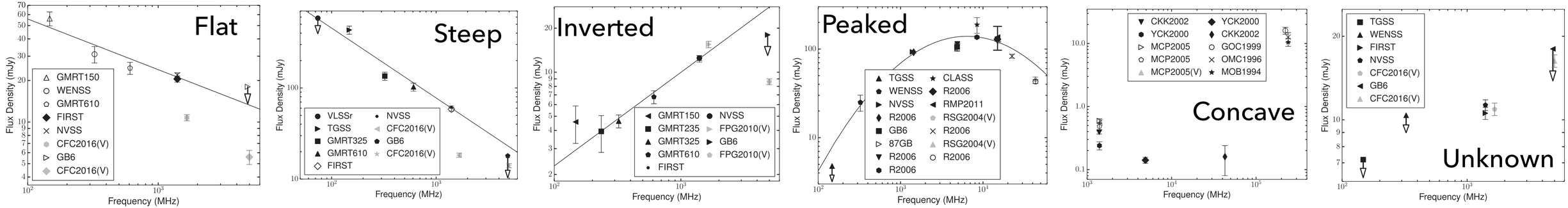
Mao+17

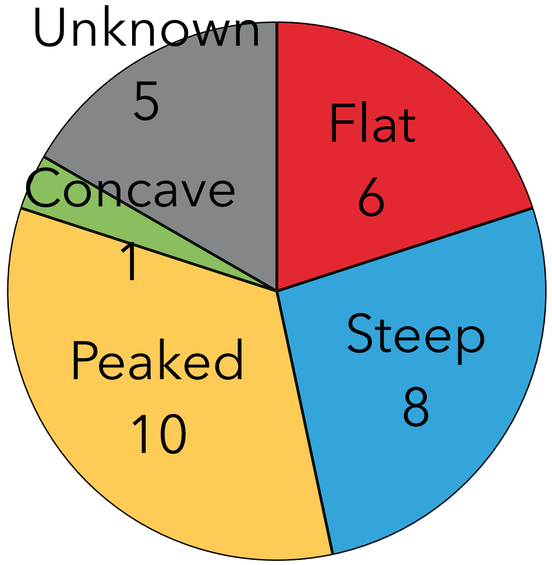


Observational approach at High-z

Statistical discussion of Wide-band radio spectrum for 30 VLBI detected AGN jets at z≥4.5

(Coppejans+17)





The distribution of spectral class

○ <u>The number of FSRQ is less than that of other types</u>

→ **<u>The cosmological evolution/An environmental effect in the early Universe?</u>**

[Problem]

- **The selection criteria are not uniform.**

→ The detection limit in radio or optical catalogs.

→The redshift criteria.

Objective

We will discuss the following two things with Flux limited VLBI sample of high-z AGN jets

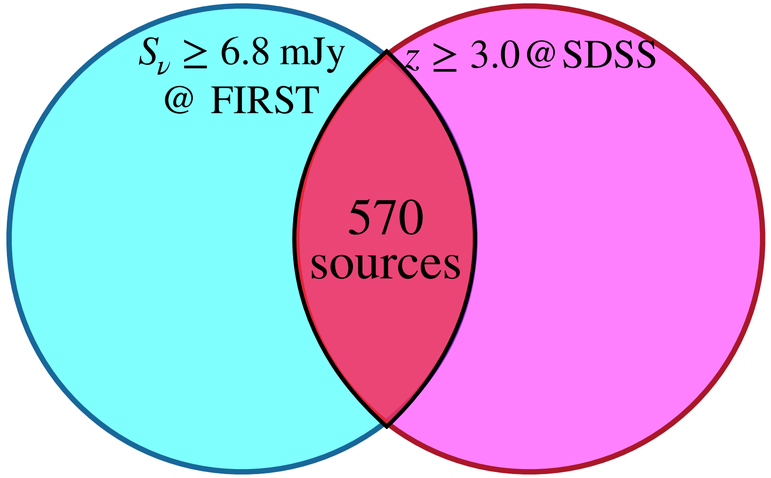
1. The distribution of high-z AGN jets classified by radio spectrum.
   >> Does selection-bias affects the distribution in the previous study?
2. Cosmological evolution for high-z FSRQs.
   >> Does the space density of the FSRQs at high-z follow the LDDE model expected at low-z?

○ Selection criteria

- z ≥ 3.0 in the SDSS quasar catalog DR7/DR10 and S ≥ 6.8 mJy in the FIRST catalog.

  → **570** targets were selected.

570 targets have been observed with JVN/YI.



The large survey of high-z AGN jets

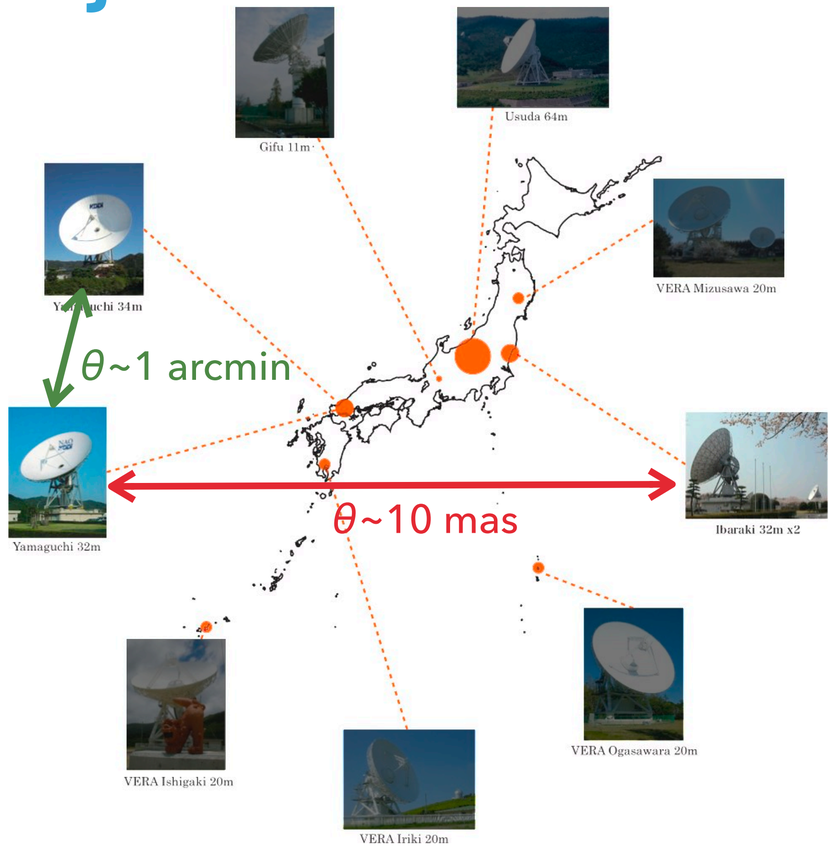
JVN: The survey of radio source originated by AGN jets.

[Strength]

- Weak radio emission (a few mJy) can be detected.
- Bright emission from 10 mas can be detected.

YI: Measurement of total flux density of AGN jets.

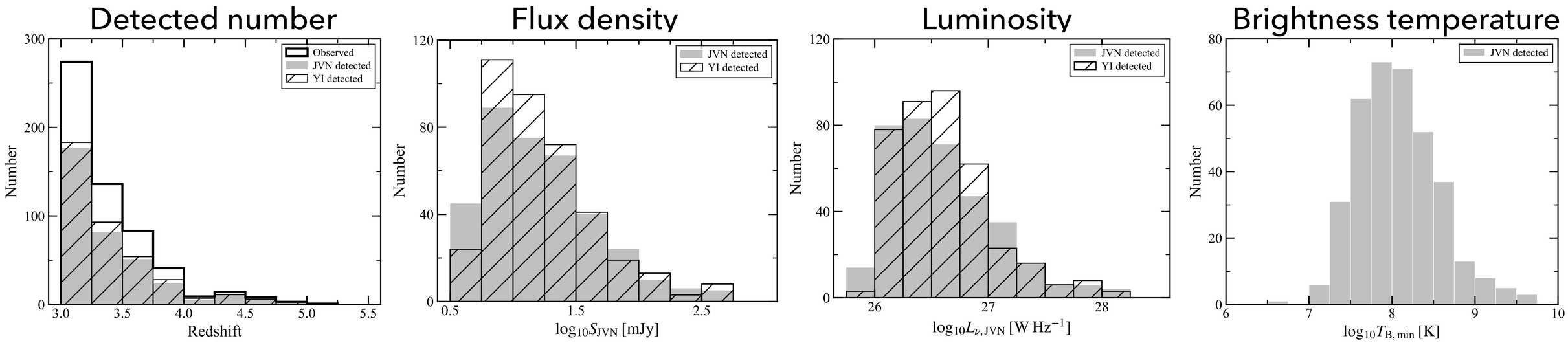
- Total ("Radio core" + "Jet") flux density can be measured.
- Discuss radio spectrum by comparing YI flux density with other radio data.



Observation parameters

Array (Telescope)	Frequency [MHz]	Polarization	Fringe spacing	Sensitivity 1σ [mJy]	Detection criteria
JVN (Yamaguchi-32m/Hitachi)	8192–8704	RHCP	8.4 mas	0.53	SNR≥7.0
YI (Yamaguchi-32m/34m)		LHCP	1.1 arcmin	0.90	SNR≥6.0

RESULT: 363 targets have been detected!



- **363 and 386** out of 570 targets have been detected by JVN, YI (z=3.0–5.3).

$$T_{\rm B,min} = 1.61 \times 10^{11} S_\nu \theta^{-2} (1+z) \quad {\rm K}$$

$$L_\nu = 1.20 \times 10^{26} D_L^2 S_\nu (1+z)^{-1} \quad {\rm W\ Hz^{-1}}$$

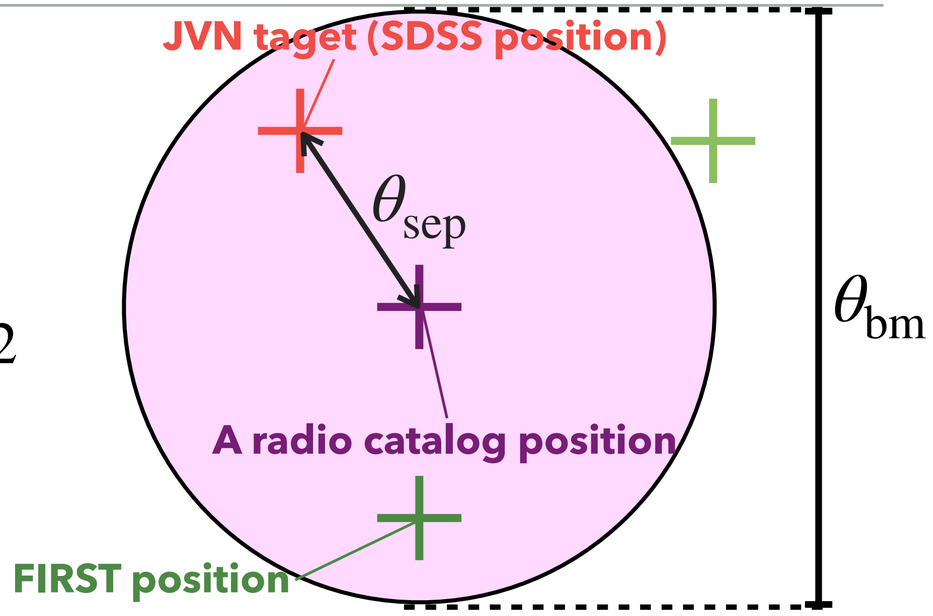
- The brightness temperature is higher than **10^6 K** for all target detected by JVN.

→ **<u>The VLBI flux density is originated by AGN jets.</u>**

Classification by the wide-band radio spectrum

○ Identification criteria

- The positional error between target's positions: $\theta_{\rm sep} \leq \theta_{\rm bm}/2$
- If there are some FIRST sources within $\theta_{\rm bm}$, the source in the radio catalog may be contaminated.

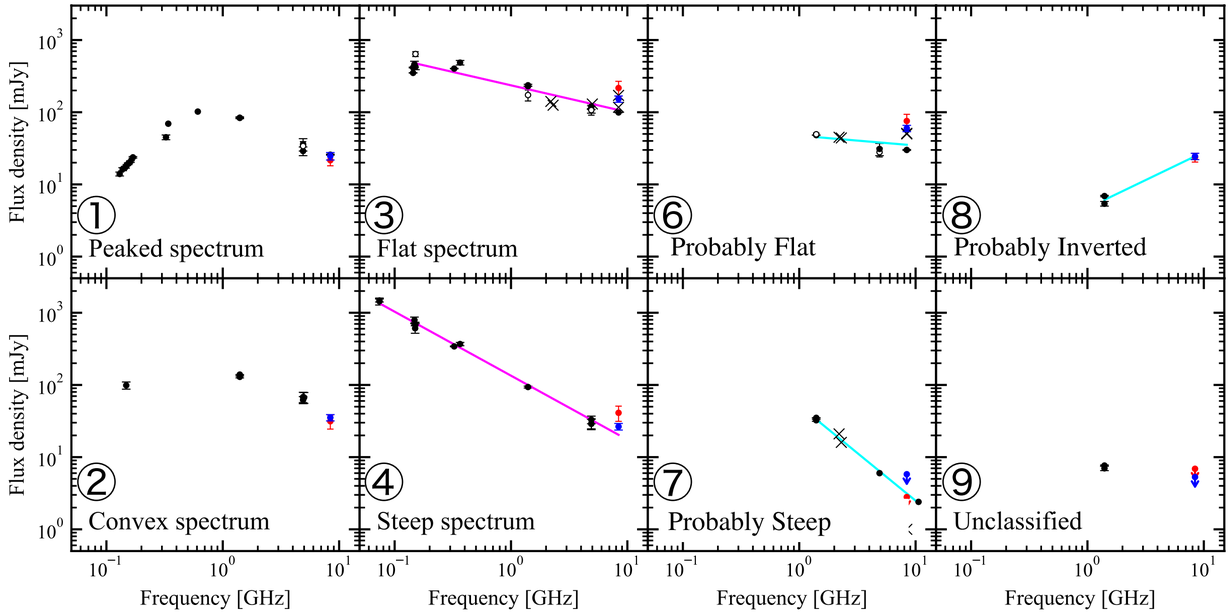


A Illustration of identification between target and a radio catalog sources.

○ Spectral classification

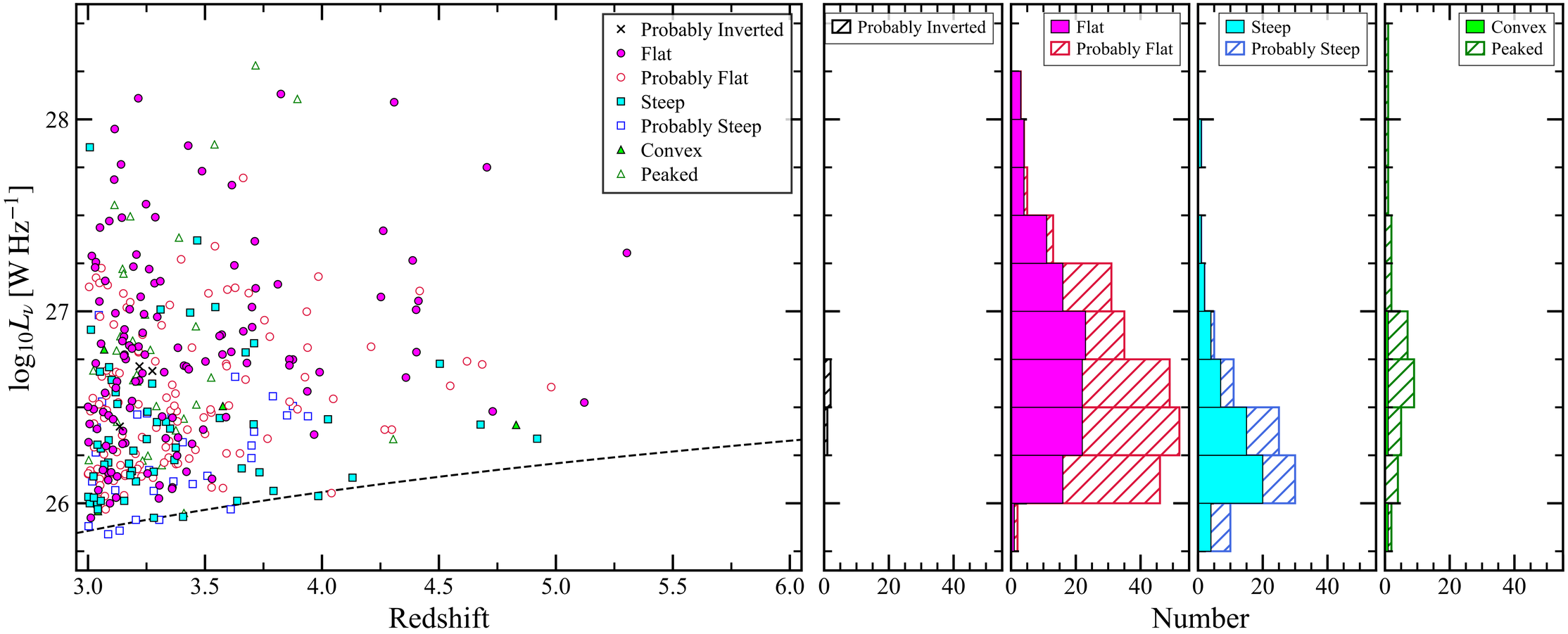
- Targets have been classified 9 classes with the radio spectrum

Classification	Criteria
① Peaked spectrum	With turnover point
② Convex spectrum	Convex like shape
③ Flat spectrum	Spectral index at $\lvert\alpha\rvert \leq 0.5$
④ Steep spectrum	Spectral index at $\alpha < -0.5$
⑤ Inverted spectrum	Spectral index at $\alpha > 0.5$
⑥ Probably Flat	Spectral index at $\lvert\alpha\rvert \leq 0.5$ (at GHz)
⑦ Probably Steep	Spectral index at $\alpha < -0.5$ (at GHz)
⑧ Probably Inverted	Spectral index at $\alpha > 0.5$ (at GHz)
⑨ Unclassified	Less than 2 data points



Redshift distribution of the spectral classification

	Flat	Probably Flat	Steep	Probably Steep	Probably Inverted	Inverted	Peaked	Convex	Unclassified
Observed	134	127	153	39	3	0	39	6	69
JVN detected	122	118	54	31	3	0	31	4	0



Space density of Flat type spectrum

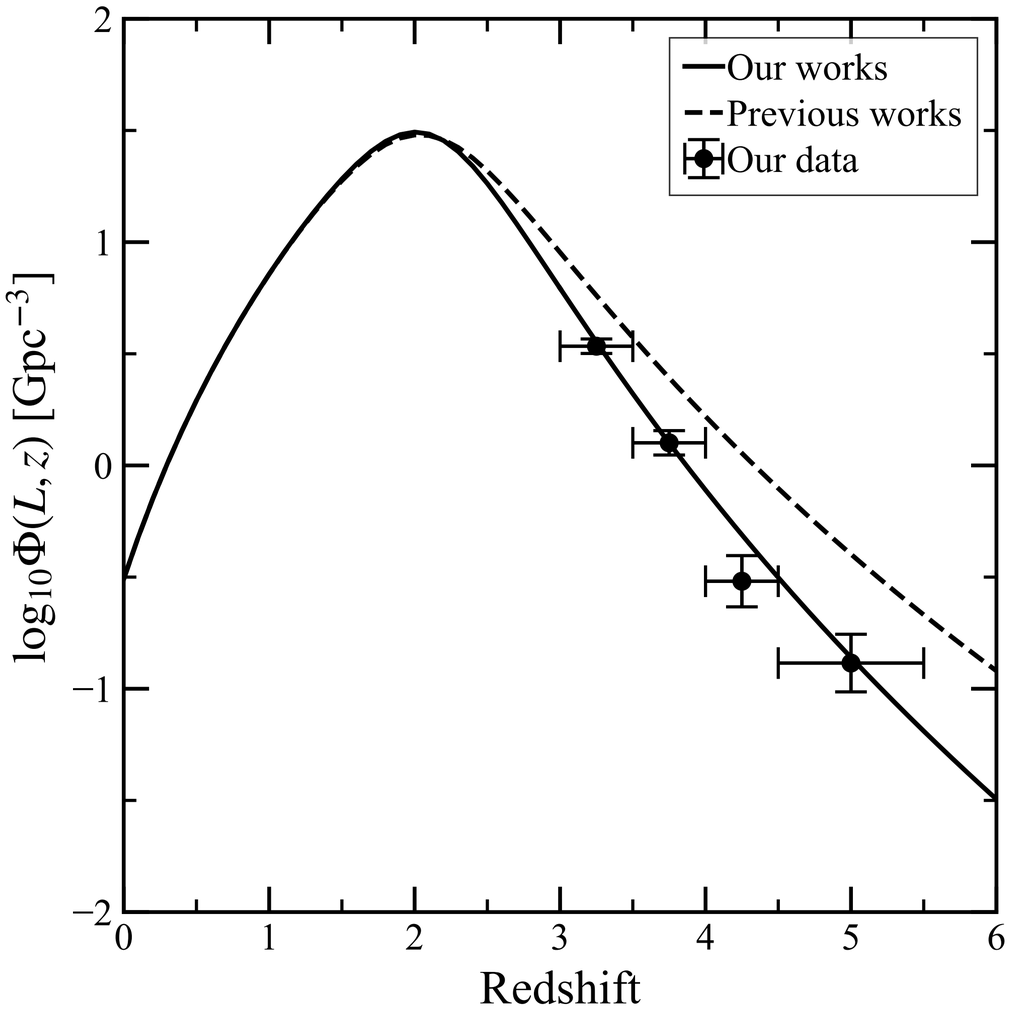
Comparing the space density of our targets with LDDE model best-fitted in z ≤ 3.

Fit the LDDE model, A, p_2 to the space density of our target

$$\Phi(L,z) = \frac{A}{\ln(10)L}\left[\left(\frac{L}{L_*}\right)^{\gamma_1} + \left(\frac{L}{L_*}\right)^{\gamma_2}\right]^{-1} \times \left[\left(\frac{1+z}{1+z_c^*(L/L_f)^{\alpha}}\right)^{p_1} + \left(\frac{1+z}{1+z_c^*(L/L_f)^{\alpha}}\right)^{p_2}\right]^{-1}$$

LDDE model parameters

	# Source	z range	γ_1	L_* [erg s-1]	γ_2	z_c^*	α	p_1	p_2	A [Gpc-3 erg-1 s]
Mao+17	168	0.0–5.3	0.67	6.00×10^{43}	1.69	1.94	0.08	4.54	−7.81	7.35×10^{-2}
Our study	271	3.0–5.3	0.67	6.00×10^{43}	1.69	1.94	0.08	4.54	**−9.48**	**7.05×10^{2}**



Our space density shows the similar **trend** in previous stud

However, p_2 in our study is **steeper than** one in previous stu

Space density of Flat type spectrum

Comparing the space density of our targets with LDDE model best-fitted in z ≤ 3.

Fit the LDDE model, A, p_2 to the space density of our targets.

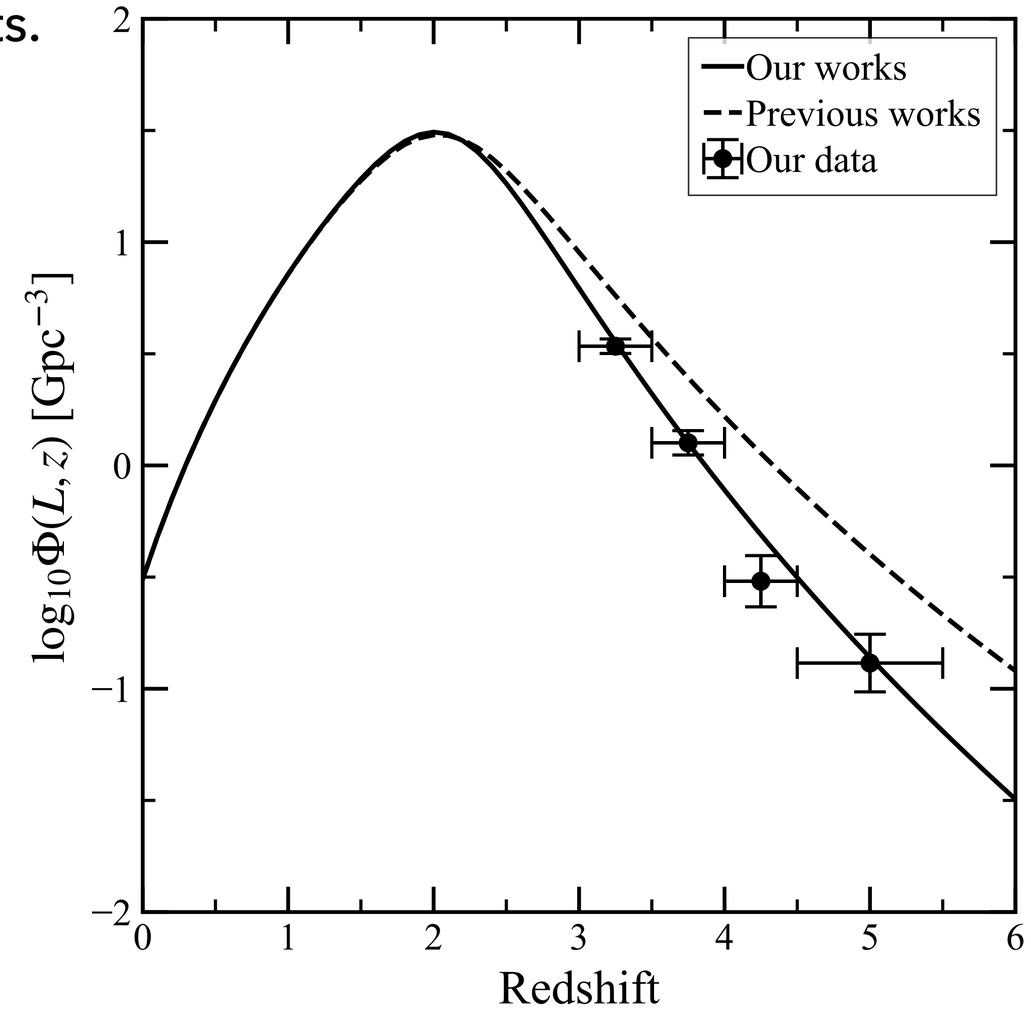
[Strength in our study]

- The uniformity of the selection criteria.
- The large number of the targets.

[In previous study]

- Targets were selected by a lot of criteria.
- Only 5 targets in the sample at z ≥ 3 and the luminosity range $\log L = 43.16 — 45.21$ erg s^{-1}.

Space density at high-z is different from the low-z prediction.



VLBI imaging with EAVN

Other problem of high-z AGN jets.

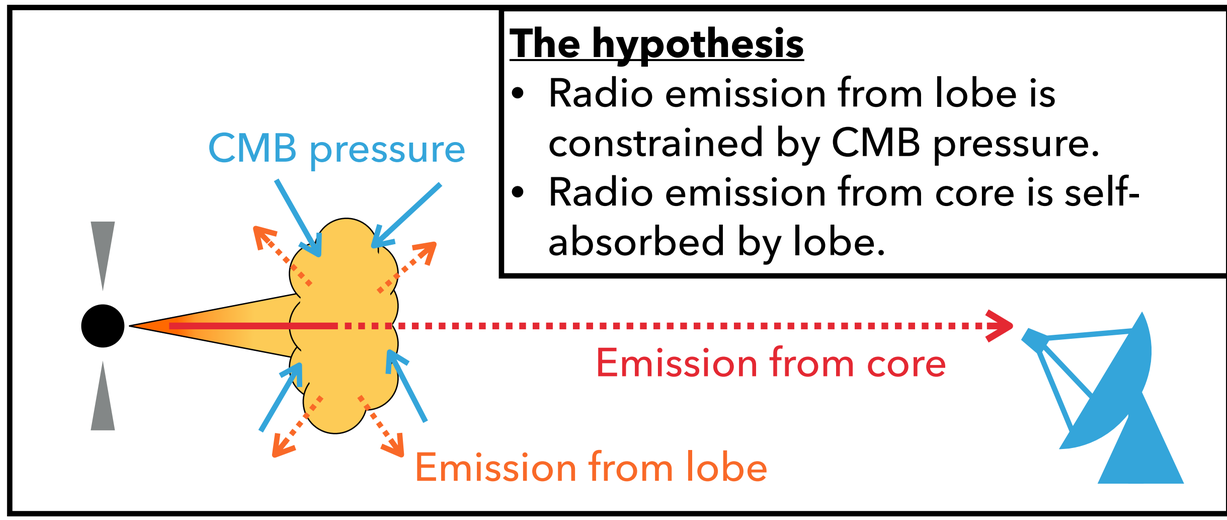
- Lorentz factor of high-z AGN jet is lower than that at low-z AGN jet.
- It is depended on environment in the early Universe.

We have observed 8 high-z AGN jets with EAVN.

(Furuya Y., Niinuma K., Fujisawa K., Hada K., Shen Z.-Q., Zhang, Y.-K.)

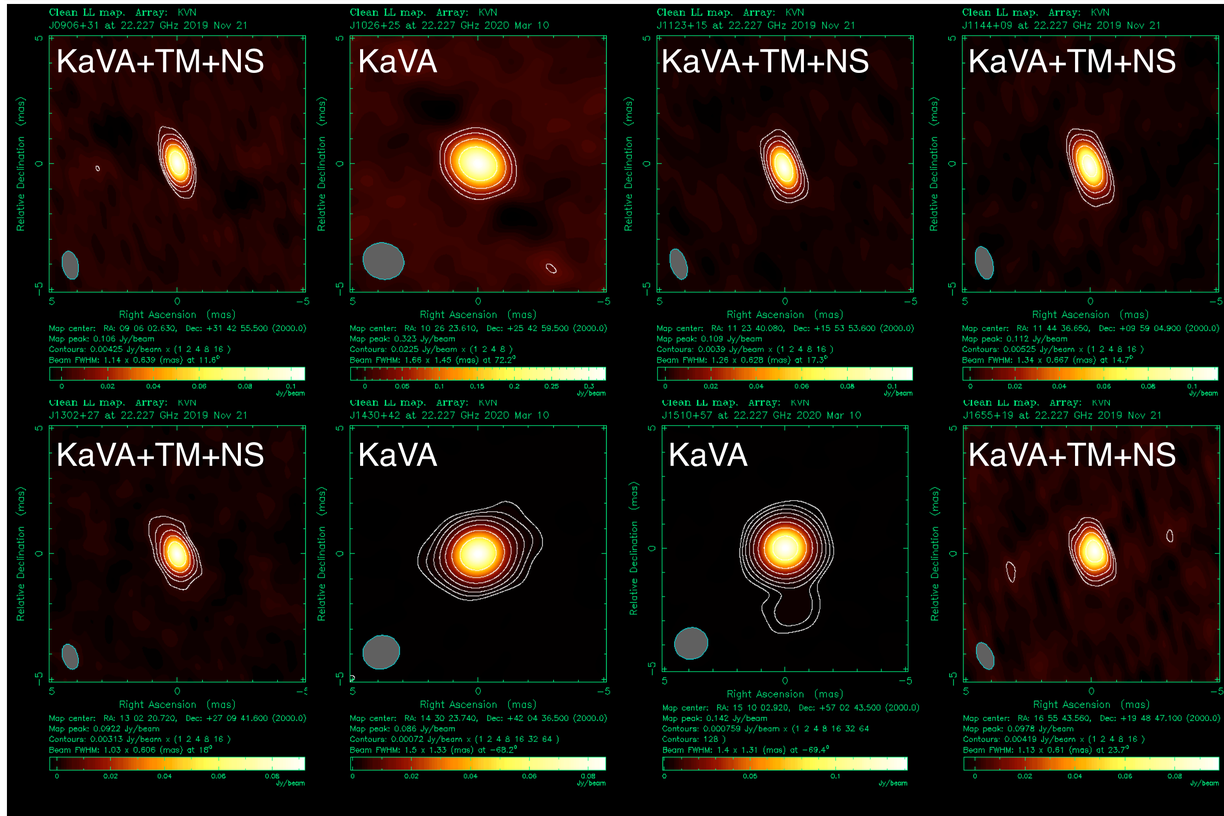
- 8 targets have been imaged by EAVN.
- Some target have an pc-scale jet at ~100 GHz (at rest frame)

These are key targets to reveal a radiation mechanism in the early Universe.



The hypothesis

- Radio emission from lobe is constrained by CMB pressure.
- Radio emission from core is self-absorbed by lobe.



SUMMARY

○ **<u>Problems: Selection bias affects studies of cosmological evolution.</u>**

[1] Current LDDE model is only consistent with the result at low-/mid-z.

[2] The number of FSRQ is less than that of other types

○ **<u>Our study: A large Flux limited VLBI sample at z≥3 have been obtained.</u>**

[1] → Space density of high-z FSRQ is different from the predicted one at low-z.

(= The environment around FSRQs is different at different redshift.)

[2] → Flat spectrum is majority at high-z.

(= The distribution of spectral types is affected by selection-bias in previous study.)

○ **<u>Future work: Discuss physical parameter from VLBI images observed by EAVN.</u>**

[3] Feature of high-z FSRQs might be affected by an environmental effect.

→ We are going to discuss the physical parameter from VLBI images at ~100 GHz (the rest frame).