VLBI study of peaked-spectrum high-redshift AGN

Tao An(antao@shao.ac.cn), Ailing Wang, Yingkang Zhang (SHAO, China)
Yulia Sotnikova, Timur Mufakharov, Marat Mingaliev, Alexander Mikhailov
Vladislav Stolyarov, Anastasya Kudryashova (SAO, Russia)

Background

Observing HzAGN at radio wavelengths provides important clues about the growth of SMBHs and the evolution of AGN in the early universe. Current optical surveys have made great progress in the search for high-redshift quasars, and in the future JWST expects to be able to detect more and fainter high-redshift galaxies. Less than 10% of the optically selected HzAGN has radio emission, but the origin of the radio emission is still in debate (jets? galactic-scale star formation? nuclear winds?). At the same time, progress is also made in the discovery of HzAGNs in X-ray bands, and most of the X-ray selected AGNs are blazars. The radio emission from high-z blazars is clearly jet-dominated. Due to the extreme distance, revealing the inner radio structure of HzAGN requires high-resolution imaging by VLBI.

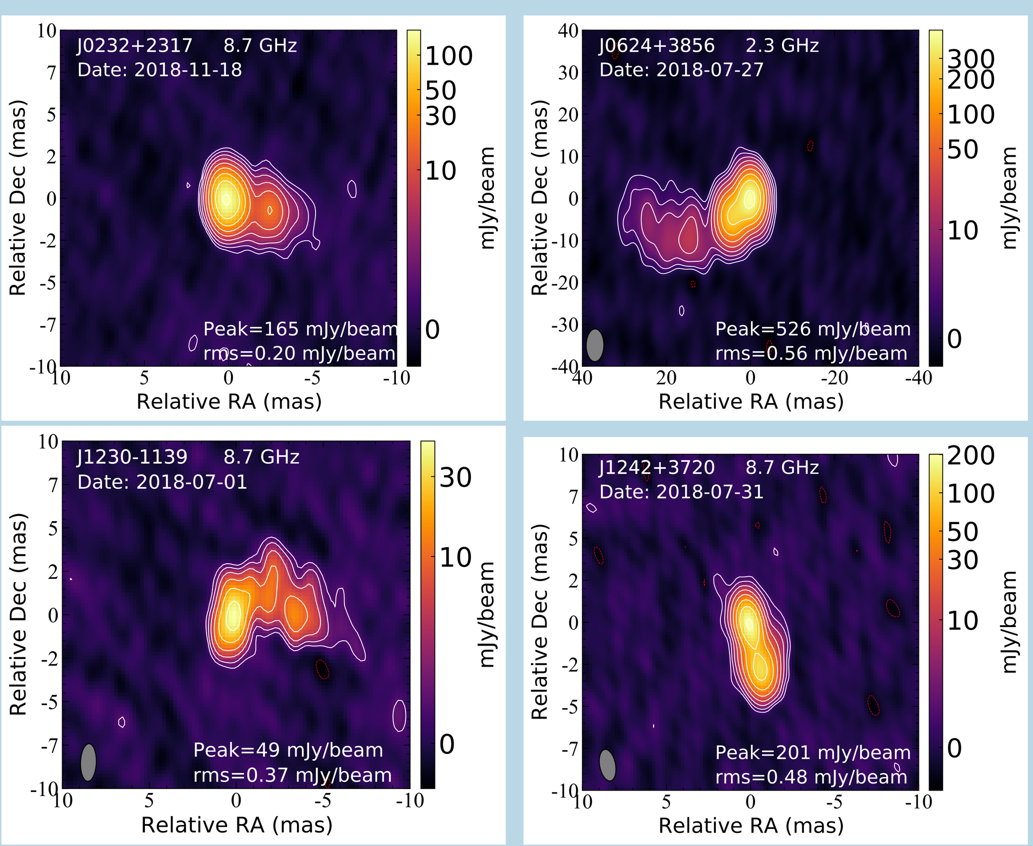
Sample and Plan

In addition to direct mapping to study the jet structure, radio spectrum is also a common method to study the nature of radio emission. RATAN-600 has the capability of (quasi)-simultaneous multi-band monitoring of AGN, and the obtained radio spectra provide valuable data for studying high-redshift AGN. The RATAN-600 monitoring sample includes over 10,000 blazars and the observations started in 2006 till now. The RATAN-600 project aims at studying the radio continuum spectra, variability, radio loudness and identifying GPS/MPS candidates.

Among the monitoring sample, there are 102 z>=3 quasars with 1.4GHz flux density higher than 100mJy. They have monitoring data for multiple epochs. The series of the research:

1. Radio spectra of the sample[1]. Interestingly, the sources show diverse radio spectral types: peaked spectrum (46%), flat, steep, complex, upturn, rising. The study reveals that a peaked spectral shape (PS) is a common feature for bright high-redshift quasars. Most are highly radio-loud with log R > 2.5.
2. Radio flux density variability and the spectrum shape variation[2].
3. VLBI imaging study of the 47 peaked spectrum sources[3] and comparing their mas-scale radio properties with those flat-spectrum ones.

The combined VLBI imaging and single-dish data provide a rich perspective for studying the radio properties of HzAGN.



Abstract

High-redshift AGN (HzAGN) are closely associated with the first generation of active SMBHs in the Universe and are the key to revealing the black hole accretion and jet properties in the early Universe. Limited by sensitivity, current radio observational studies of HzAGN focus on radio-loud AGN. We recently analyzed multi-frequency (2.3-22 GHz) and quasi-simultaneous RATAN-600 data, from which a sample of 102 z>3 quasars was selected. It shows that about 50% of the sample have peaked spectra; such a high percentage exceeds that of the low redshift AGN and cannot be explained simply by selection effects. These HzAGN have blazar-type beamed jets but inverted spectra of misaligned radio sources, probably indicating that this is a common feature of the earliest AGN whose radio activity has just been excited. We are conducting high-resolution VLBI imaging of this sample, combining radio spectra, jet structure, and jet kinematics to gain insight into the radio emission properties of the HzAGN. The future super sensitivity and high resolution of SKA-VLBI are expected to observe more HzAGN with weak radio emission, offering opportunities for studying the radio activity of SMBHs at the cosmic dawn and the jet feedback to early galaxies, the interstellar environment of early galaxies, and the cosmological evolution of the radio luminosity function.

An example

A compact symmetric radio source born at 1/10 the current age of the Universe[4]

J1606+3124 is tentatively identified as a radio galaxy with a redshift of 4.56, at an era of one-tenth the current age of the Universe. Its RATAN-600 data show a radio spectrum peaking around 3 GHz. The VLBI image shows a compact triple structure with a projected size of 68 parsecs. The radio properties of J1606+3124, including the edge-brightening morphology, GHz peaked radio spectrum, slow variability, and low jet velocity, consistently indicates that it is a compact symmetric object (young radio galaxy). The kinematic age of J1606+3124 3600 yr supports it is a young radio source with ultra-high jet power. Infrared observations show that it lives in a gas- and dust-rich host galaxy environment, which may hinder the growth of the jet. If its redshift and galaxy classification can be confirmed by further optical spectroscopic observations, J1606+3124 will be the highest redshift CSO galaxy known to date.

High-resolution low-frequency VLBI, such as the International LOFAR Telescope and the SKA-Low, has the potential to detect the extended emission if it is indeed present. Current radio observations of distant objects can only detect unusually bright AGN and/or massive BHs that accrete near the Eddington limit. The SKA and ngVLA are expected to detect a large number of weak radio sources at high redshifts, crucial for improving our understanding of the co-evolution of SMBHs and galaxies in the early Universe.

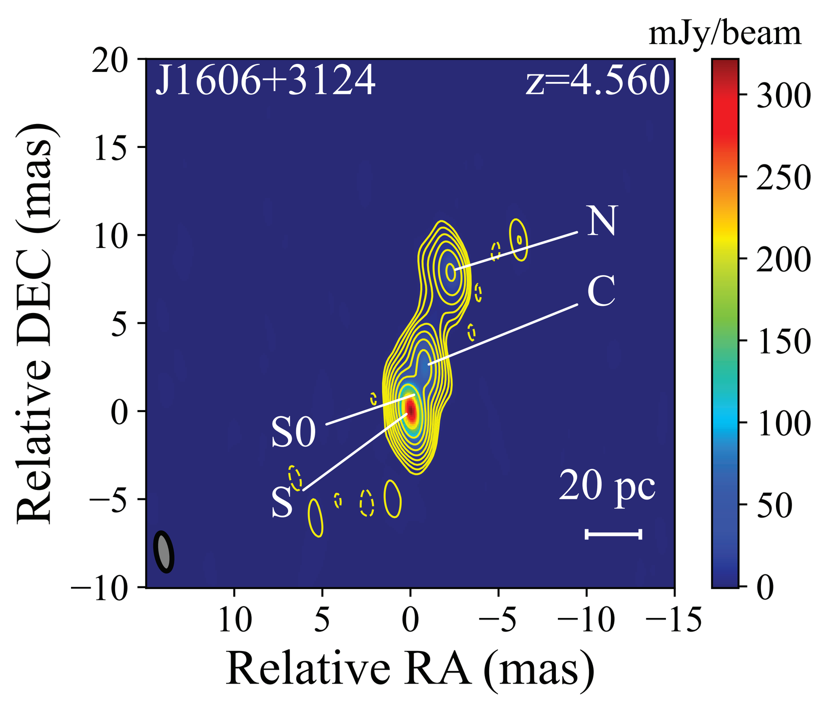


Figure 2: VLBI image of J1606+3124.

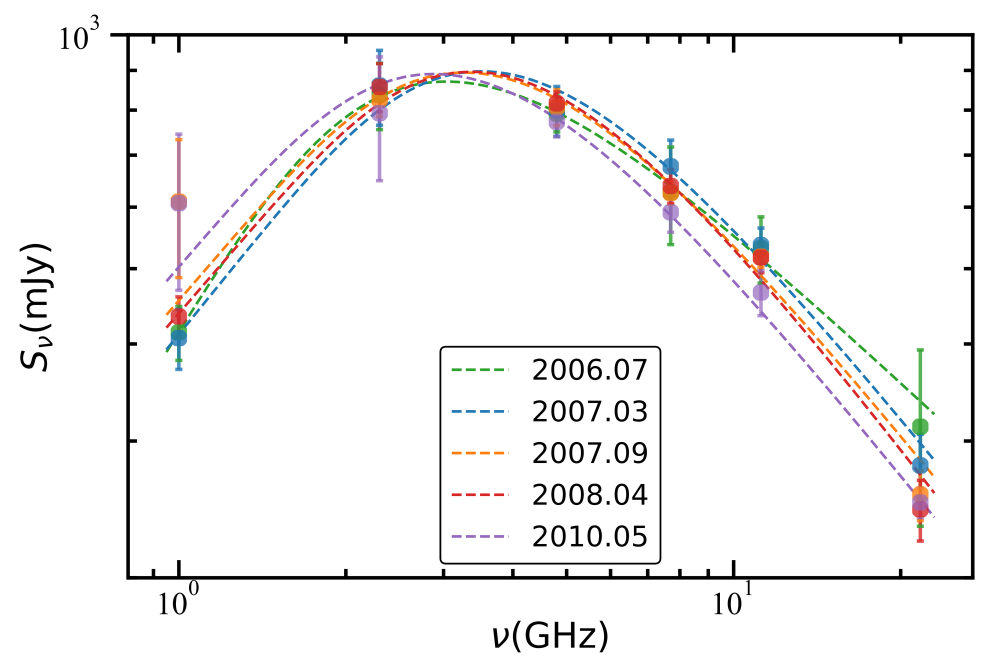


Figure 3: Radio spectra of J1606+3124 at five epochs.

Future Plan in the long run

1. studying the radio variability of the selected z>3 quasar sample[3]
2. searching for peaked spectrum at extremely high redshifts using SKA-low (e.g., MWA, LOFAR) precursor data (with turnover frequency at hundreds MHz)
3. high sensitivity VLBI imaging of the peaked spectrum sources : (1) mapping the optically thin jet at 1.6 and 5 GHz; (2) mapping the radio structure with SKA-Low VLBI (or international LOFAR) around the peak frequency 300MHz. ; (3) relic lobes left from multiple episodes of AGN activity
4. multi-wavelength study of high-z blazars: radio, infrared, X-ray, gamma-ray.
5. Finding high-redshift CSO sources in the high-redshift Universe is the starting point for studying the evolution of FRII-type galaxies at their redshifts. CSOs should be more abundant than blazars, therefore, it is more important to reveal the radio properties of high-z CSOs to fully understand the cosmic evolution of radio-loud AGN.

References

[1] Sotnikova Y., Mikhailov A., Mufakharov T., et al., 2021, MNRAS, 508, 2798. High-redshift quasars at z > 3 - II. Radio spectra
[2] Sotnikova Y. et al. in prep. High-redshift quasars at z > 3 - II. Radio variability
[3] An T. et al. in prep. High-redshift quasars at z > 3 - III. parsec-scale structure
[4] An T., Wang A., Zhang Y., 2022, MNRAS in press. doi:10.1093/mnras/stac205