Dual-frequency EVN Observations of a Large Sample of Distant Radio Quasars

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Motivation: High-redshift quasars hold one of the keys to understanding of evolution of galaxies and supermassive black holes in the early Universe. They can also be used for cosmological tests. The quasars detectable at this distance provide insight into the properties, e.g., the mass and accretion rate, of the earliest, most massive (~$10^9 M_\odot$) black holes (Sbarrato 2021, Galaxies, 9, 2). However, the list of known objects above redshift ~4 is still rather limited. To study the nature of these high-redshift radio sources as a class, we need to expand the sample. Previous studies like Volonteri et al. (2011, MNRAS 416, 216) showed that at high-redshifts, blazars seem to be in majority compared to radio quasars with misaligned jets. High-resolution milliarcsecond-scale observations of blazar candidates (identified via X-ray measurements) reveal more and more extended, or even symmetric radio structures with steep spectra instead of the main blazar characteristics like compact radio cores with flat spectra and Doppler-boosted emission. Very long baseline interferometry (VLBI) offers an opportunity to classify the already known high-redshift radio sources more definitively. VLBI studies of these sources might help to understand why many misaligned sources are actually ''missing''. In addition to the VLBI observations the recent *Gaia* EDR3 optical astrometric positions also help in the classification process as they can distinguish between compact symmetric objects (CSOs) and core-jet sources.

The sample: We have selected 13 z>4 radio quasars from Sbarrato et al. (2013, MNRAS, 433, 2182) which have not yet been imaged with VLBI. All these sources are present in the FIRST catalogue (White et al. 1997, ApJ 475, 479) with flux densities in the range ~1—100 mJy. Dual-frequency VLBI observations were carried out with the e-EVN at 1.7 and 5 GHz. With only a few dozens of radio quasars at z>4 imaged with VLBI to date, our sample increases the sample substantially. Our VLBI data provide essential information on the source compactness, brightness temperatures and spectral properties. Below we present some preliminary highlights of the study.

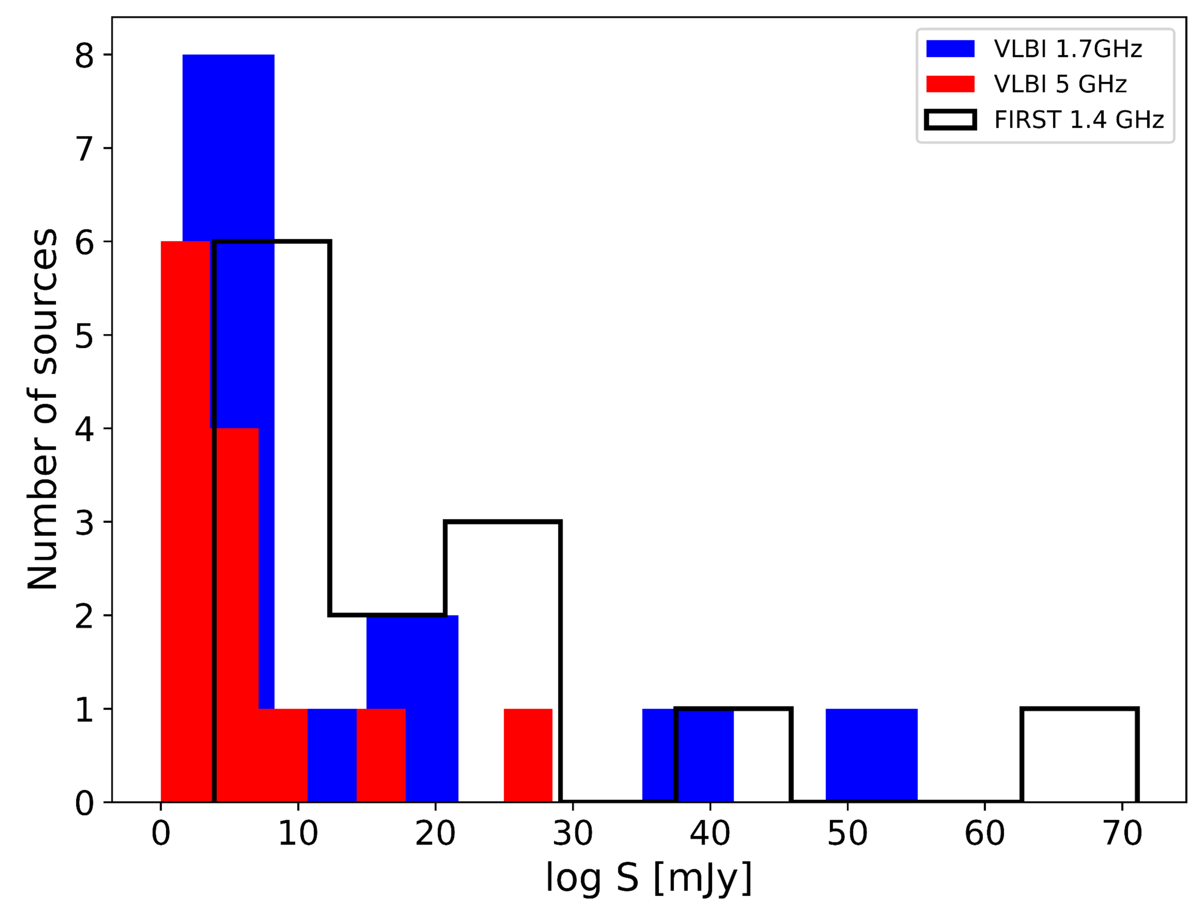

Fig 1.: The flux density distribution of the 13 radio sources in this study. *Black:* FIRST flux densities at 1.4 GHz. *Blue:* EVN 1.7 GHz flux densities. *Red:* EVN 5 GHz flux densities.

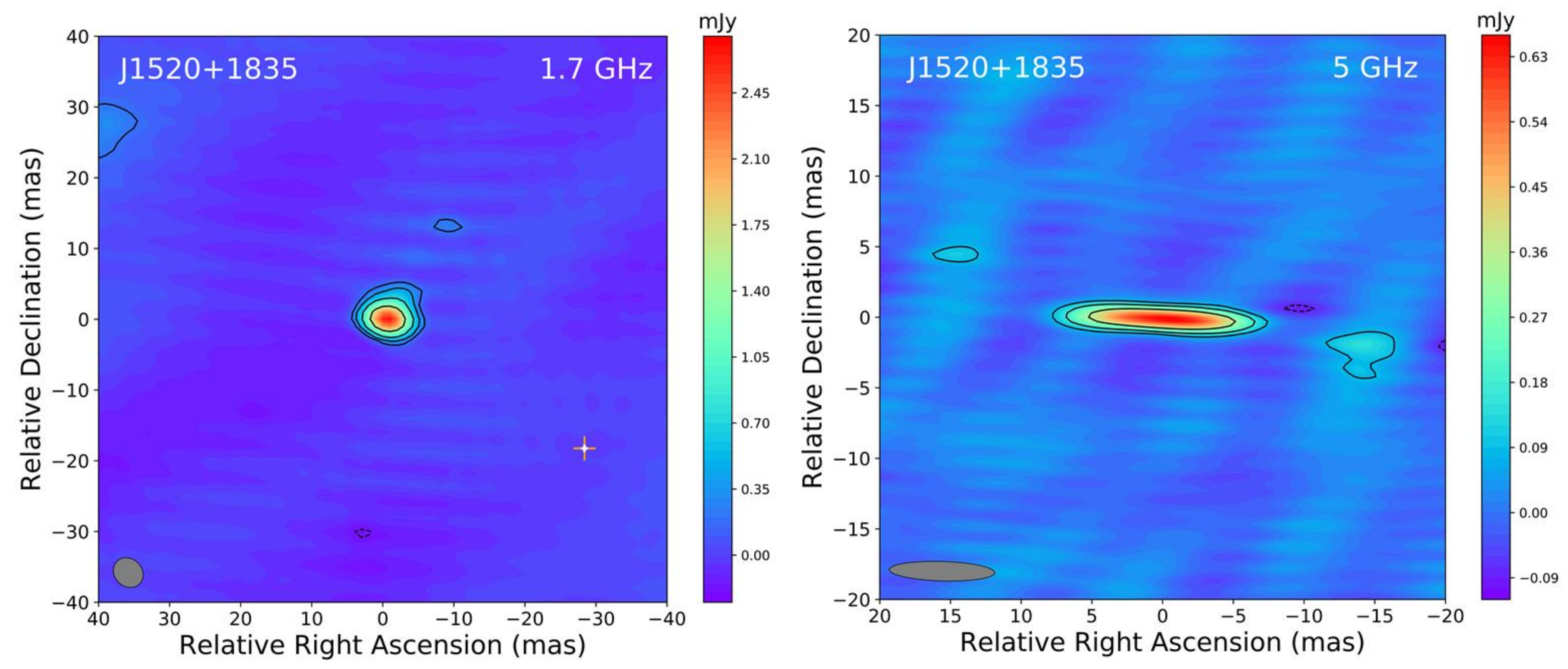

Fig 2.: EVN radio images of *J1520+1835* (z = 4.1) at 1.7 and 5 GHz. The orange cross in the left figure marks the *Gaia* optical position. The white symbol size represents the uncertainty. *Left:* The peak intensity is 2.7 mJy beam^{-1} and the lowest contours are drawn at ±0.4 mJy beam^{-1} (3 times the rms), the positive contour levels increase by a factor of 2. *Right*: The peak intensity is 0.7 mJy beam^{-1} and the lowest contours are drawn at ±0.1 mJy beam^{-1}.

J1520+1835: The source *J1520+1835* is one of the most interesting targets in the sample. An intriguing feature is the location of the *Gaia* EDR3 optical position related to the detected radio emission. The optical peak is located ~30 mas SW to the 5 GHz VLBI position which corresponds to ~250 pc projected linear offset at redshift z=4.12. This offset suggests a young radio source where the radio emission may originate from a compact hot spot inside the radio lobe. The measured ultra-steep spectrum and the lack of Doppler-boosted emission also support this picture.

J1006+4627: *J1006+4627* is a typical blazar source with a flat spectrum and high brightness temperature suggesting that the jet emission is Doppler-boosted. The *Gaia* position of this source shows an offset with the VLBI one, but not as large as large as for *J1520+1835*. The VLBI component detected with the EVN might be a compact core.

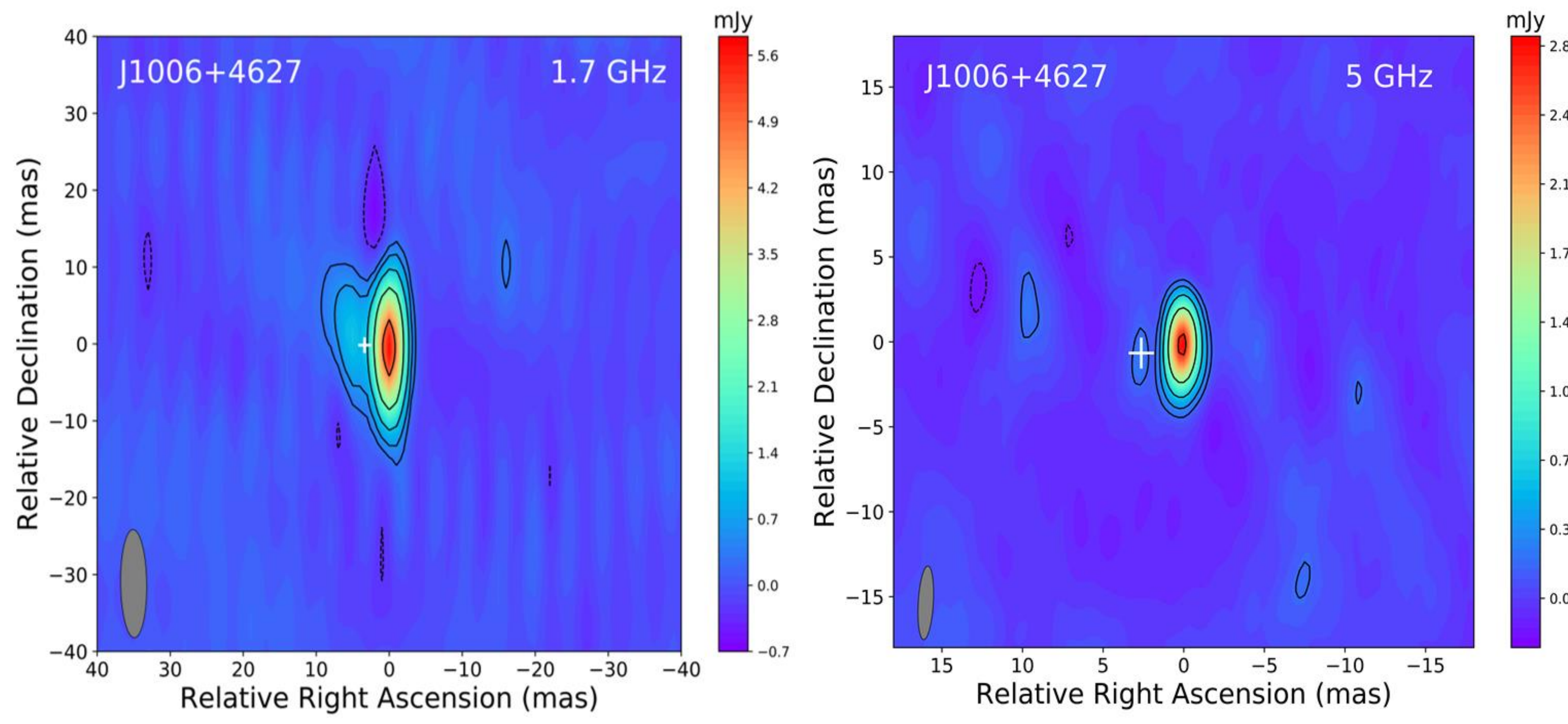

Fig 3.: EVN radio images of *J1006+4627* (z = 4.4) at 1.7 and 5 GHz. The white symbol represents the *Gaia* optical position. *Left:* The peak intensity is 6.9 mJy beam^{-1} and the lowest contours are drawn at ±0.7 mJy beam^{-1} (3 times the rms), the positive contour levels increase by a factor of 2. *Right*: The peak intensity is 2.7 mJy beam^{-1} and the lowest contours are drawn at ±0.35 mJy beam^{-1}.

Preliminary results: All 13 targets in our project were successfully detected with EVN. Based on the VLBI data, we derived their brightness temperature and monochromatic radio luminosity. We were able to determine the two-point spectral index between 1.7 and 5 GHz for the compact structure for 11 sources: 6 of them have flat and 5 of them have steep spectra. We also compared our measurements with low-resolution flux densities available in the literature, enabling us to construct/investigate the radio continuum spectra. Our findings indicate that roughly half of the sources are blazar-like objects with core-jet structures and flat spectra while the others are unbeamed gigahertz-peaked spectum sources or CSOs.

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