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Radio Jet Proper Motion Analysis of Nine Distant Quasars above Redshift 3.5

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Objectives

High-redshift radio quasars (HRQ) are believed to hold key information on the rapid growth of the first supermassive black holes (SMBHs) and their co-evolution with the host galaxies. Up to now, jet kinematic studies of radio quasars have hardly reached beyond the redshift range at $z > 3.5$. This significantly limits our knowledge of high-redshift jets. In this work, we selected 9 radio-loud quasars at $z > 3.5$ which display milliarcsec-scale jet morphology. We show evidence of their jetted nature by presenting high-resolution very long baseline interferometry (VLBI) images of the sample at 8.4 GHz frequency and making spectral index maps. We also consider Gaia optical positions that are available for 7 out of the 9 quasars, for a better identification of the jet components within the radio structures. We also obtained jet component proper motions of the sample and estimated the jet kinematic and geometric parameters (Doppler factor, Lorentz factor, viewing angle).

The VLBI sample of high-z quasars

We searched through the Astrogeo database (`http://astrogeo.org/`) to build our sample. To select HRQs that meet our need for jet kinematic studies, the following selection criteria are applied:

- The redshift is $3.5 \lesssim z \lesssim 4.5$.
- The source should be compact and bright (i.e. $S_{\mathrm{VLBI},8.4} > 50$ mJy)
- The source should have well resolved jets in the 8.4-GHz archival images.
- The source should have more than 3 archival epochs spanning a sufficiently long (at least ~ 10 yr) time range. This increases the chance for detecting jet movements at high redshifts.

We selected 9 sources as a result (see table 1). To provide robust high-resolution structure and component identification of the sample, we also proposed separate VLBA observation (project code: BZ064) on 2017 February 5 and 2017 March 19.

Name	z	N_{epoch}	Epoch range	Redshift reference
J0048+0640	3.580	5	2004–2018	Gurvits et al. (1999)
J0753+4231	3.595	4	1995–2018	Hewett & Wild (2010)
J1230−1139	3.528	3	1996–2018	Drinkwater et al. (1997)
J1316+6726	3.515	4	1995–2018	Richards et al. (2009)
J1421−0643	3.689	5	1997–2018	Ellison et al. (2001)
J1445+0958	3.552	6	1997–2018	Hewett & Wild (2010)
J1606+3124	4.560	4	1996–2018	Healey et al. (2008)
J1939−1002	3.787	5	1996–2019	Lanzetta et al. (1991)
J2102+6015	4.575	4	1994–2018	Sowards-Emmerd et al. (2004)

Table 1:The selected target sources for this study.

Results and summary

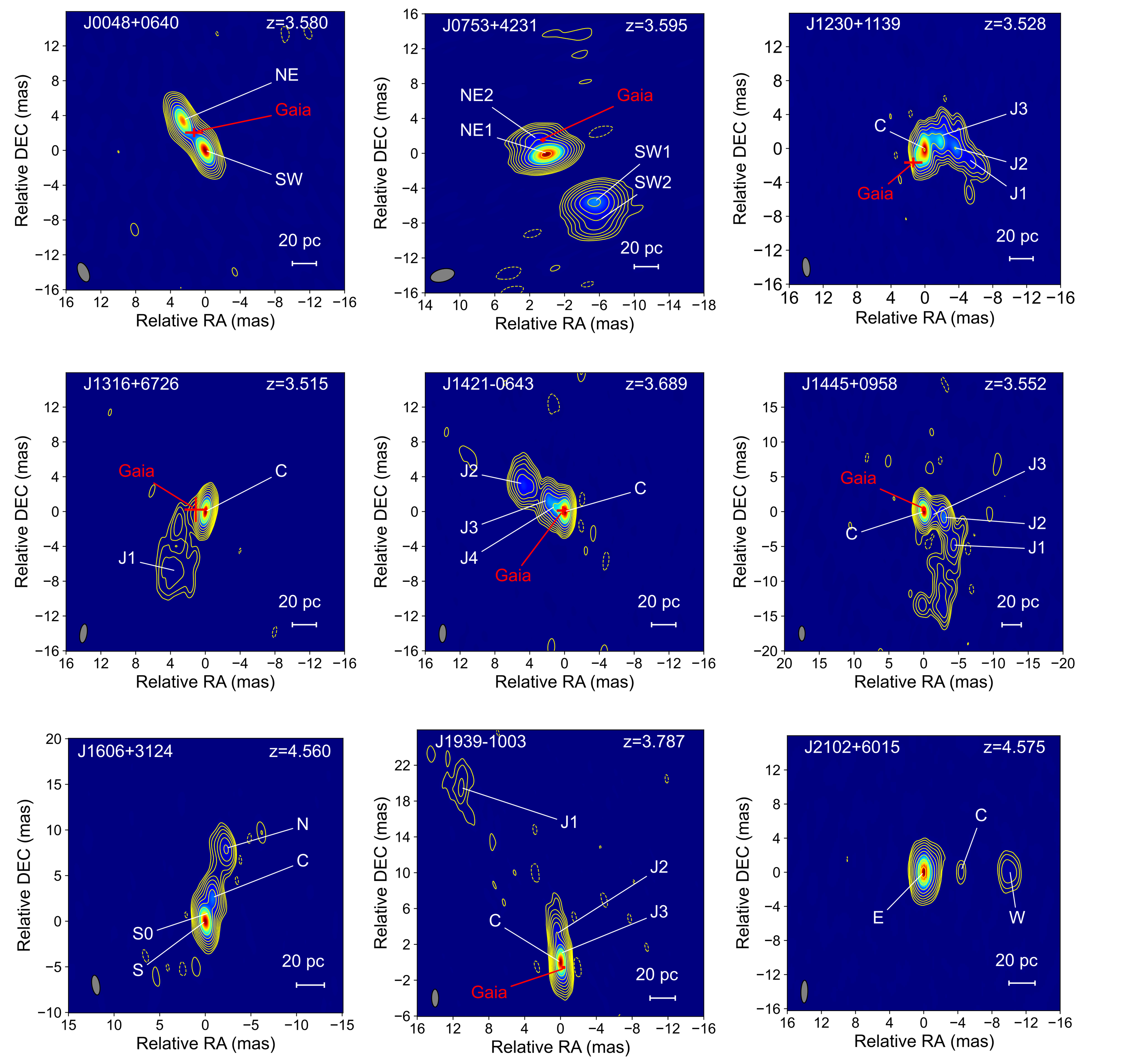
- We present the high-resolution VLBI images at 8.4 GHz, the spectral index maps from archival dual-band (2.3 GHz and 8.4 GHz) VLBI data and the Gaia detection of the optical positions (7 of 9 sources). See figures 1 and 2.
- Based on the results above, we identified six sources (J0753+4231, J1230−1139, J1316+6726, J1421−0643, J1445+0958, and J1939−1002) as core–jet blazars and three sources (J0048+0640, J1606+3124 and J2102+6015) as CSO (compact symmetric object) or CSO candidates. For the CSO nature of J1606+3124 and J2102+6015, separate papers have been published based on VLBI results [1,2]
- We estimated jet proper motions in the sample. The apparent jet component speeds in the core–jet sources are in the range of $1.4 - 17.5\,c$, consistent with the known proper motions in low-redshift radio-loud quasars [e.g. 3,4].
- Our study helps populating the high-redshift end of the apparent proper motion–redshift diagram with reliable jet proper motions measured with VLBI. Consistently with earlier studies, we found that large values of β_{app} only appear at low redshifts.

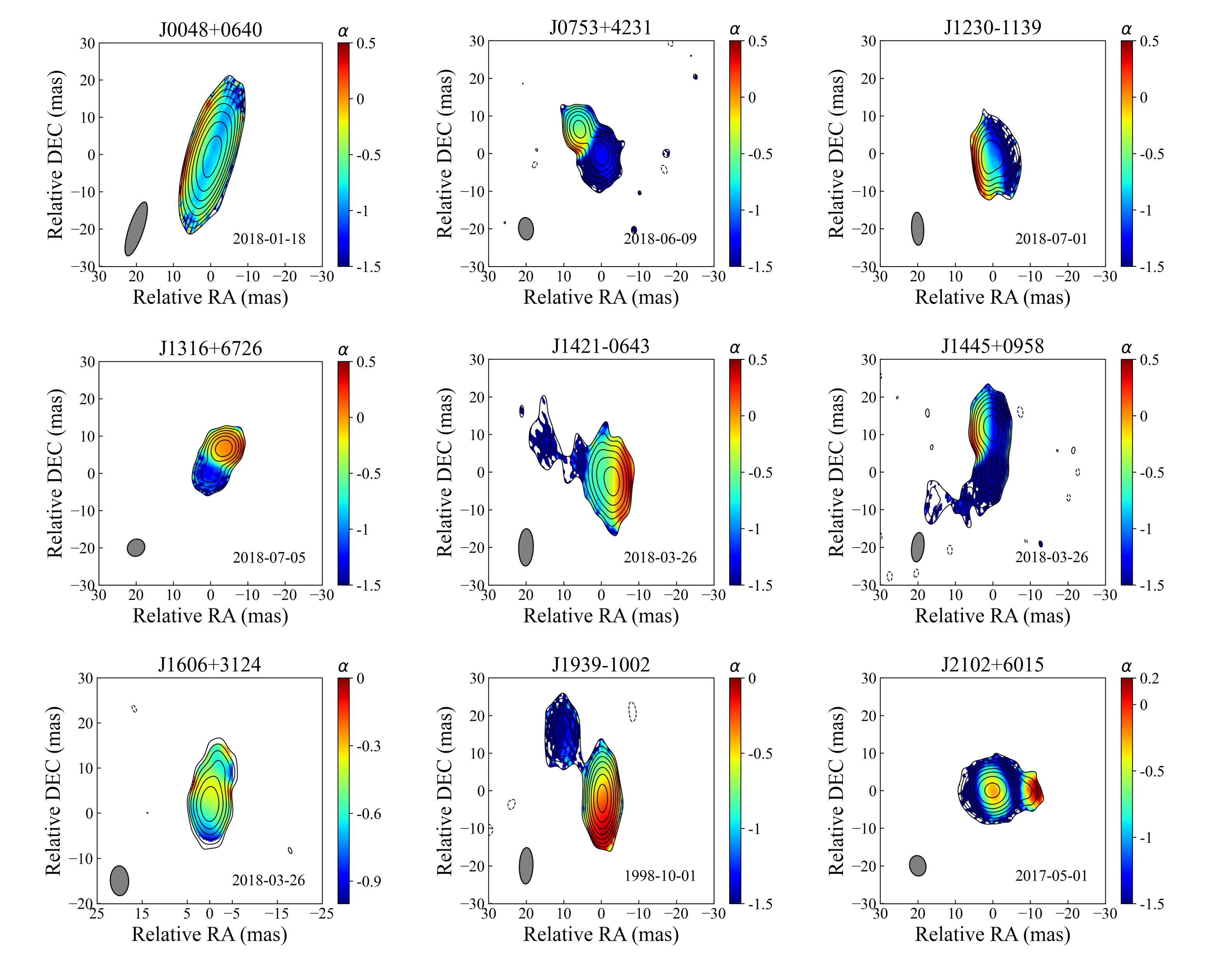
Extra information

- The work has been submitted to ApJ.
- For more detailed information, please contact ykzhang@shao.ac.cn

Figure 1 (the upper 9 images) presents the naturally weighted images of the 9 high-redshift sources after deep cleaning, derived from our VLBA observations at 8.4 GHz in 2017. The lowest contours represent ± 4 times of the rms noise, and the positive contour levels increase by a factor of 2. The red crosses mark the optical positions detected by Gaia, the bar lengths are 3 times the Gaia positional errors. A flat Λ Cold Dark Matter (ΛCDM) model of $\Omega_{\mathrm{m}} = 0.27$, $\Omega_\Lambda = 0.73$, and $H_0 = 70$ km s^{-1}Mpc^{-1} is used to generate the physical scales in the maps (shown in the bottom-right '20 pc' bar).

Figure 2 (the lower 9 images) shows the spectral index maps of our sample, based on simultaneous 2.3- and 8.4-GHz observations (The spectral index α is defined as $F \propto \nu^{\alpha}$, where F is the flux density, ν the frequency). In each map, the background contours represent the 2.3-GHz image. They start from 3 times of its rms noise and increase by a factor of 2. The bottom-left ellipse are the restoring beams of the 2.3-GHz map and the epochs used for the imaging are shown at bottom right.





References

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