Follow-up of 3C48 position change at 0.06 arcsec

1 Introduction

Analysis of a routine IVS VLBI experiment R4844 observed on 2018.05.31 showed position of 3C48 shifted at -57.70 mas ± 0.50 mas in declination and 1.54 mas ± 0.42 mas in right ascension with respect to its previous position determined over the period of 1990–2017. Last time when 3C48 was observed with VLBI and had normal positions was on 2017.06.26, IVS experiment R1798. Source position jitter at a level of 0.1–1.0 mas is not unusual, but a shift at $0.06''$ is extraordinary. Data analysis procedure was carefully checked to rule out hardware/software/correlator problems. When position of 3C48 is estimated, postfit residuals of 10 group delays of 3C48 acquired in that experiments at baselines 6000-7000 km long have a scatter 0.05–0.2 ns, similar to the scatter of 82 other sources observed in R4844 experiment. Without estimation of 3C48 positions and using their a priori values derived from analysis of prior observations of this source, group delays of 3C48 become outliers at a 3–6 ns level, over 100 times the wrms of post-fit results. This is not consistent with hardware failures.

An et al. (2010) has presented the multifrequency VLBI images that of 3C48 at 1.6, 4.85, 8.43 and 15 GHz. The image at 8.43 GHz showed three compact components at X-band, A, B, and B2 (See Figure 1), component A being 55.2 mas south of the component B. An et al. (2010) have demonstrated that A is the core. In 2004.06.05, components A and B at 8.3 GHz were equally compact, $\theta_{\max}$ 1.18 and 1.34 mas respectively, but component A (the core) was weaker than component B: 18.1 mJy versus 55.8 mJy.

Figure 1: VLBA image of 3C48 observed at 1.5 and 8.3 GHz on 2004.06.05 epoch from An et al. (2010). Panel a) shows the 1.5 GHz image characterized by a number of bright knots embedded in the jet body and extended emission toward the East. Three bright compact components are detected in Panel f), labeled as A, B and B2. The component A is associated with the core, B and B2 are hotspots. The component A is further resolved into two sub-components, A1 (core) and A2 (inner jet).

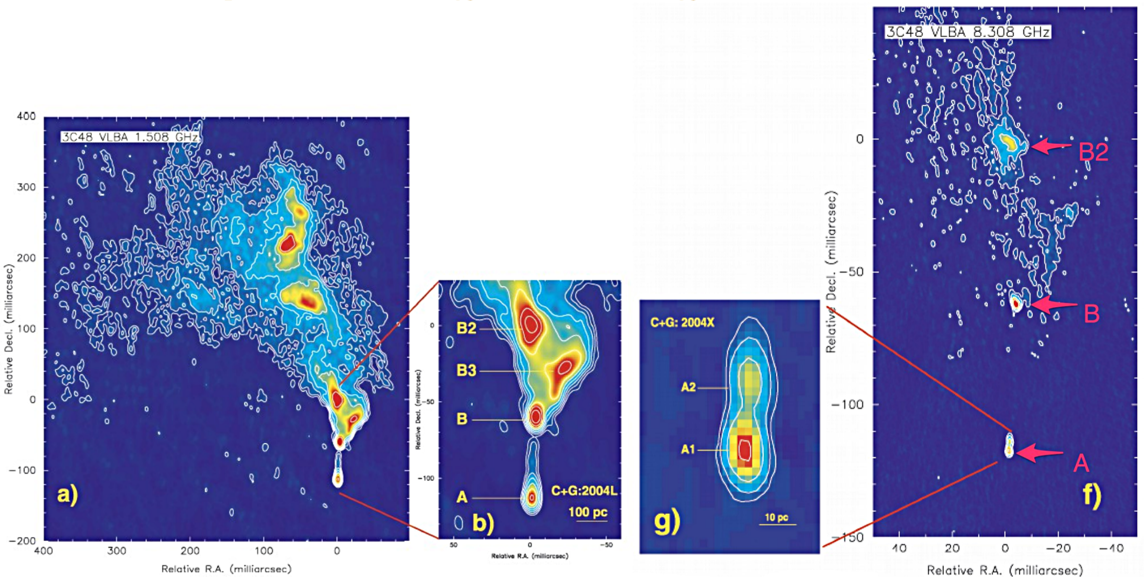


Table 1 shows estimates of 3C48 positions. We see that X-band position differs from S-band position by 51.5 mas. The X-band position is within of 0.7 mas of Gaia positions. The most plausible explanation is that prior 2018 B-component dominated, and fringe fitting process picked B-component.

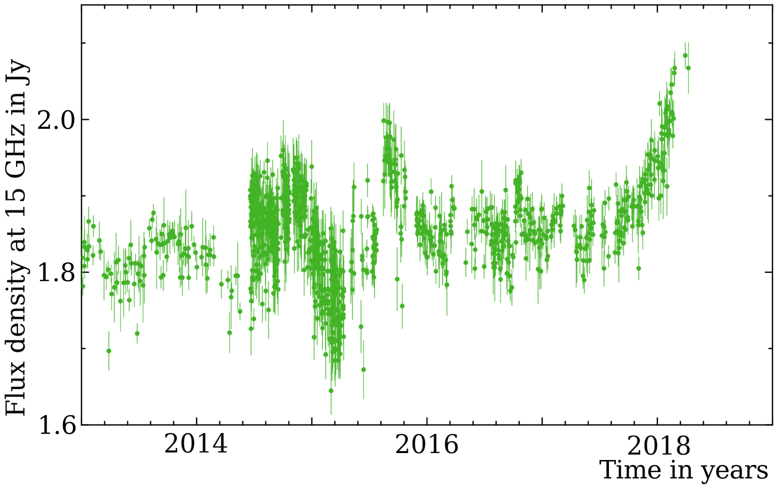
Table 1: Estimates of 3C48 positions

			RA J2000.0	$\sigma(\alpha)$ mas	DEC J2000.0	$\sigma(\delta)$ mas
3C48	J0137+3309	VLBI prior 2018 X/S	01 37 41.299543	0.34	+33 09 35.13377	0.44
3C48	J0137+3309	VLBI on 2018.05.31 X/S	01 37 41.299646	0.42	+33 09 35.07607	0.50
3C48	J0137+3309	VLBI on 2018.05.31 S	01 37 41.299644	1.57	+33 09 35.13236	3.40
3C48	J0137+3309	VLBI on 2018.05.31 X	01 37 41.299644	0.39	+33 09 35.08074	0.44
3C48	J0137+3309	Gaia DR2	01 37 41.299625	0.05	+33 09 35.07998	0.05

Then in 2018 a flare in the core happened (See Figure 2, and component A became brighter than B and X-band, but remained relatively weak at S-band. The fringe fitting process picked component A at X-band and component B at S-band. There is a possibility that prior 2018 B2 dominated and then the flare happened in the hotspot B.

Experiment r4844 was processed by the USNO, and unfortunately neither visibility, nor calibration information is available. But even this information were available, 10 visibilities is not sufficient to make a meaningful image of such a complex source.

Figure 2: 3C48 lightcurve at 15 GHz from the OVRO monitoring program (courtesy of S. Kiehlmann and the OVRO team).



A rough estimate of the flux density (SNR 9.4 reached over 390 s integration time at baseline HART15M/WETZELL) is 100–200 mJy at both X and S-bands.

2 Why new observation is needed

We ask for 4 hours of VLBA time and propose to observe 3C48 in order to get a high-quality image during the flare phase, determine its absolute and differential positions, spectral energy distribution of components, and core-shifts of components A, B, and B_2. Flares at AGNs are common, but we argue 3C48 is a special case and deserves dedicated observations.

First, a flare that shifts position estimate at a mind-blowing 58 mas is extraordinary. We cannot sweep such a case under the carpet. This event will go to textbooks. The source was observed since 1990.01.29, had stable astrometric position related to the component B (or B2) for at least 28 years. A sudden gigantic change warrants detailed investigation **during the flaring stage**, because other less prominent position changes may be overlooked. 3C48 is the excellent case when the position change is the largest. It may happen that the flaring component will return to its normal state very soon and then future astrometric observations will again provide positions of another component that is 55.2 mas away if proper data reduction for source structure is not made.

Second, 3C48 is used as a primary VLA flux calibrator. If our hypothesis about the flare will be confirmed, the source might be demoted from the status of a primary calibrator. Anyway, changes in flux density of a primary calibrator seem to be a matter of primary importance.

Third, 3C48 has been well studied in the past. The source was observed with VLBA in 1996.01.20 and 2004.06.25 and with EVN on 2005.06.07. These observations revealed superluminal motion of A2 component of 3.74 ± 0.35 c and tentatively motion of B2 component with $\beta = 1.4 \pm 0.3$ c. A new epoch expands the timeline of 22 years from 1996 to 2018, during this period, A2 should move by 3.6 mas, corresponding to 2 times the beam size at 8 GHz. Of special interest, the new observation will unveil whether there is a short-lived structural change of B associated with the flare, that may indicate emergence of new sub-component or internal turbulence in the hotspot, or there is a newly ejected inner jet associated with the flare of the core A2.

Fourth, proposed observations will determine where the flared has happened: in the core or in the hot spot. The hotspot B is a re-collimation shock beyond which the jet becomes unstable and is disrupted. The proposed observation offers a rare chance to study the fine structure of the hotspot as well as its change (if the flare happened there). The hotspot B plays a key role in understanding the energy dissipation and transition of the jet flow from superluminal in inner 250 pc to sub-luminal away from B. If the flare is associated with the core A2, we expect to detect the change of the emission structure of A2 implying the production of a new jet after the flare.

Table 3 in An et al. (2010) shows that the ratios of peak flux density of components B to component A at X-band and L-band were very close in 2004: 3.1 versus 3.2. It follows from R4844 data that this ratio is more than 1 at S-band and less than 1 at X-band. **This prompts us to suggest we observe the flare in progress: its X-band flux density rose in 2018.05.31, but S-band flux density has not yet.** Since we do not know how long 3C48 will be in the elevated state since May 2018, **we request prompt observations to catch the flare.** We would like to measure the core-shift since there were indications (Plavin et al. 2017) that during strong flaring activity the equipartition state is violated and **the core-shift is changed**. Observations of the flare in progress provides us a good opportunity to test it.

Fifth, 3C48 is optically bright (G=15.83 mag) and its Gaia positions are determined with high accuracy. Therefore, Gaia position time series scheduled for release in 2022 will have very high accuracy. We expect to significant Gaia position wander caused by this flare predicted by Petrov & Kovalev (2017b). It was shown in that paper that correlation of VLBI/Gaia position difference evolution with light curves provides important information about milliarcsecond optical structure and allows to pinpoint the region whether the flare took place. Preliminary results of comparison of proper motion of VLBI/Gaia matching quasars from Gaia DR2 present an indirect evidence of the predicted jitter in Gaia AGN positions: the distribution of directions of proper motions in optical range with respect to the jet direction has strong peaks at directions along the jet or at 180° with respect to the jet direction (Petrov et al. (2018) in preparation).

The IVS has included 3C48 in the monitoring list. Thus, we will have its radio position evolution. We are submitting concurrently a RadioAstron proposal for measuring its brightness temperature.

3 Proposed observations

We propose multi-frequency observations of 3C48 and two phase calibrators at 1.6 GHz (dual-pol), 2.3/8.7 GHz (single-pol), 4.2/5.9 GHz (single-pol), and 24.3 GHz (dual-pol) with four VLBA receivers in order to determine their core-shifts and spectral energy distribution of the components. We will spread intermediate frequencies over 480 MHz bandwidth for observations at 4.2, 5.7, and 8.7 GHz in order to determine group delays with high accuracy. We will observe the calibrators in the sequence C1-T-C1-T-C2-T-C2, integrating each calibrator for 40 s and integrating the target for 100 s. It will take 36 minute to observe the sequence with four receivers. We are going to observe each multi-frequency block four times. That will results in integrating the target for 20 minutes at each frequency band. We are going to observe with 2.3/8.7 GHz a 20 minute geodetic block between the multifrequency blocks, as well as before and after them. These observations will be analyzed in three modes: a) absolute astrometry using ionosphere-free group delays of the off-beam calibrators at 2.3/8.7 GHz, 4.2/5.9 GHz, and the geodetic blocks, b) differential astrometry, and c) core-shift analysis using jet features. The objective of the first mode of analysis is to analyze the impact source structure on absolute positions of the target. In the second mode of analysis we will determine positional offsets for every pair of calibrators at each frequency band from the differential astrometry analysis. Assuming the core-shift of every off-beam calibrator is aligned along a straight line, we will be able to separate variables and determine the core-shift independent positions and the parameters of the core-shift dependence on frequency for every object. In addition, for control, in the third mode of analysis we will determine the core-shift using the jet feature method as it was done by Sokolovsky at el. (2011). We also generate RR images at 2.3, 4.2, 5.9, and 8.7 GHz as well as I Stokes images and fractional polarization at 1.6 and 24.3 GHz.

4 Project management

We waive proprietary period and ask to make the correlator output public available immediately after correlation. We are going to deliver images and perform absolute astrometry analysis within 96 hours of correlation completion. Other analyses will be finished with 6 months. Team roles: L. Petrov: scheduling, absolute astrometry and quick I Stokes imaging; K. Sokolovsky: core-shift analysis; F. Schinzel: polarization analysis, H. Krasna: investigation of effects of sources structure on astrometry; T. An: final imaging and comparision with previous images.

References

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