Jet kinematics of the blazar S5 0716+714 on different spatial scales from the multi-frequency VLBI observations

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Context

Blazar S5 0716+714 is one of the most active sources in the class. Nevertheless, VLBI kinematic studies of its jet have yielded controversial results: one kinematic scenario suggests apparent speeds of up to 20c (Bach et al. 2005, Jorstad et al. 2001), and the other suggests stationary jet with precessing ridge line (Britzen et al. 2010). We believe to have resolved this dichotomy.

Observations

We have analyzed five epochs of multi-frequency (5, 22, 43 and 86 GHz) VLBA observations of 0716+714 made in 2004. At 5 GHz, one additional epoch of observations was added to the data set, and at 86 GHz only two epochs were analyzed. Observations were carried out approximately once a month in February-August 2004, when the source was in the active state (powerful optical flare was observed in March 2004).

Observations at different frequencies allow us to sample jet of the source at different spatial scales: 22-86 GHz sample first milliarcsecond near the VLBI core while 5 GHz probe outer jet at the distance of 1-12 mas from the core. Difference in the resolution between 43 and 5 GHz is about 10 times. It is demonstrated in Fig. 1.

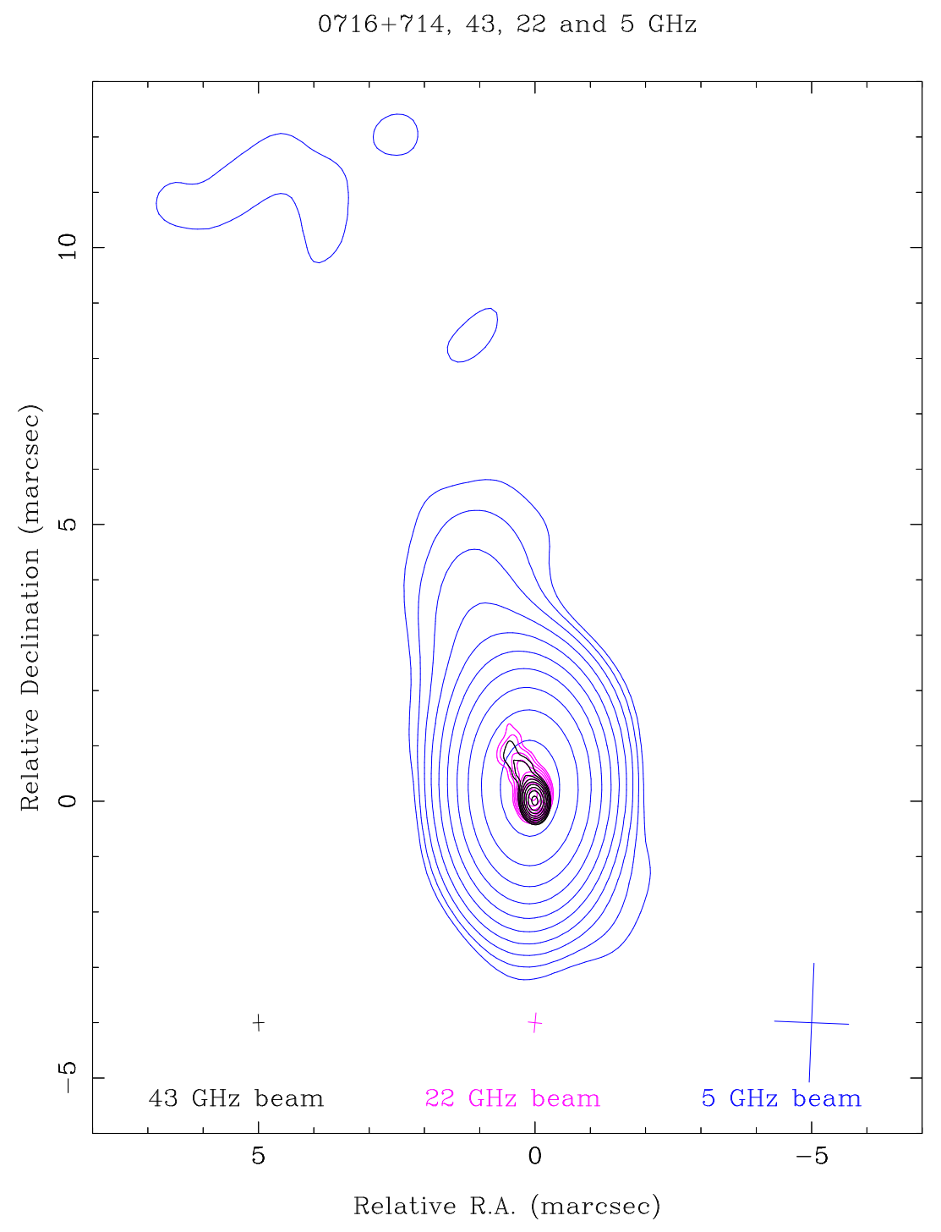

Figure 1. Contour maps of the 0716+714 at 43 GHz (black), 22 GHz (violet) and 5 GHz (blue) at the same epoch are overlaid with each other to show difference of the jet size at different frequencies. It is due to both the fact that the jet is optically thin and the resolution effect. Size of the clean beam for each frequency is shown as a cross under the image with the same colour code for resolution comparison.

Data reduction

Our aim was to identify jet components as precisely as possible. Dense time sampling gave us an advantage in the cross-identification of components between different epochs. 86-22 GHz data have very similar image resolution and probes virtually the same spatial region (inner jet). It allows us to identify the same jet components at several (3 or 2) frequencies simultaneously and thus determine their positions more accurately. For the higher frequencies we used standard CLEAN-selfcal loop in Difmap for imaging, and modelfitting with circular Gaussian components for kinematic studies. More detailed discussion of the analysis could be found in Rastorgueva et al. 2009.

For the outer jet we had only 5 GHz observations. At lower frequency jet has a smooth structure. We independently used three imaging methods which were based on different deconvolution algorithms: conventional method, based on difference mapping with the CLEAN deconvolution (Hogbom 1974), AIPS task VTESS based on the Maximum Entropy Method (MEM, Jaynes 1957, Frieden 1972) and VLBImager package based on difference mapping with Generalized MEM (GMEM) deconvolution method (Baikova 2007). The last one is a new package for the VLBI data reduction. GMEM method is designed for the reconstruction of sign-variable functions, it searches for the maximally smoothed image subject to the constrains, and gives unbiased solutions. Modelfitting with circular and elliptical Gaussian components have been performed within each method for studies of the jet kinematics. More detailed discussion of the methods use and comparison of their results you can find in the recent paper by Rastorgueva et al. 2010.

Results: inner jet

In the inner jet, we have found **three fast components with apparent speeds up to 20*c* and one stationary component** near the core. Their proper motions and apparent speeds obtained at both 43 and 22 GHz are lister in the Table 1. Note good agreement between those values. We used 43 GHz as a reference frequency since those maps have highest resolution. Fig. 2 is illustrating component motion along the jet.

Comp. name	μ, 43 GHz mas/yr	μ, 22 GHz mas/yr	β_{app}, 43 GHz c	β_{app}, 22 GHz, c c
C5	1.01±0.09	1.11±0.13	19.4±1.7	21.3±2.5
C6	1.04±0.07	0.98±0.04	16.9±1.6	18.9±0.8
C7	0.44±0.04	0.76±0.14	8.5±0.8	14.6±2.6
C8	0.00±0.01	0.12±0.02	–	–

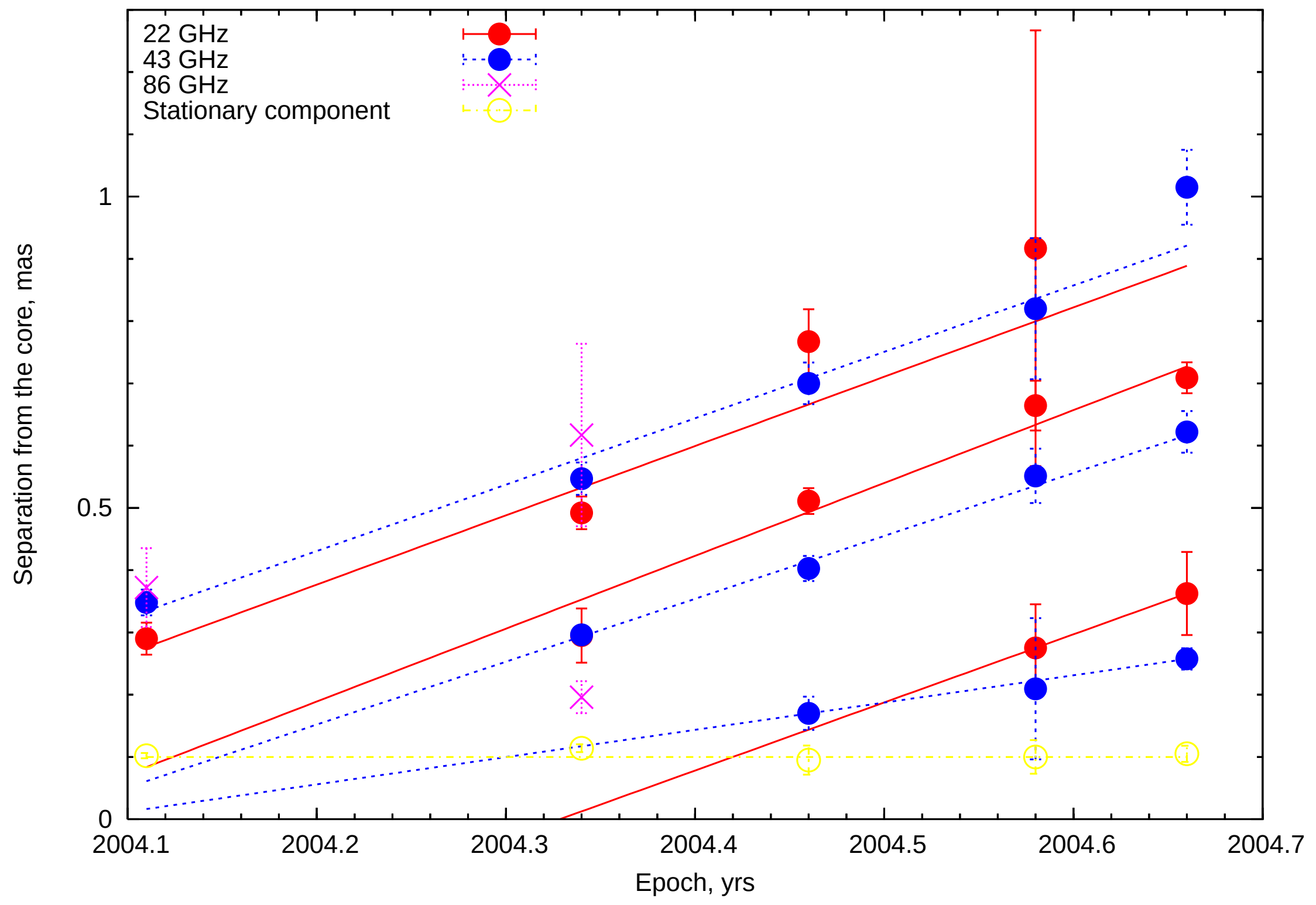

Figure 1: Linear fit to the component positions at different epochs, representing their outward motion along the jet. Components identified at 22 GHz are shown in red colour, 43 GHz in blue and 86 GHz – in violet. Yellow colour shows the stationary component C8 which is only 0.1 mas from the core. C8 positions and fit are shown as found from the 43 GHz data.

Results: large-scale jet

For the large scale jet three imaging methods yielded three kinematic scenarios. We analyzed and carefully compared them, details of this study is to be published in the paper by Rastorgueva et al. 2010. Combining results of all three methods, we found that the **large-scale jet of 0716+714 is stationary and contains four components** (named C0, C1, C2 and C3). Spatial accuracy of the method combination is 1.16 mas, and so is the uncertainty of the position determination for each of the stationary components, which approximate values could be found in the Table 2.

Comp. name	core separation, mas
C0	11.5
C1	4.6
C2	3.0
C3	1.6

Results: large-scale jet (cont.)

Fig. 3 represents results of the combination of all three methods which we used to study kinematics of 0716+714 at 5 GHz.

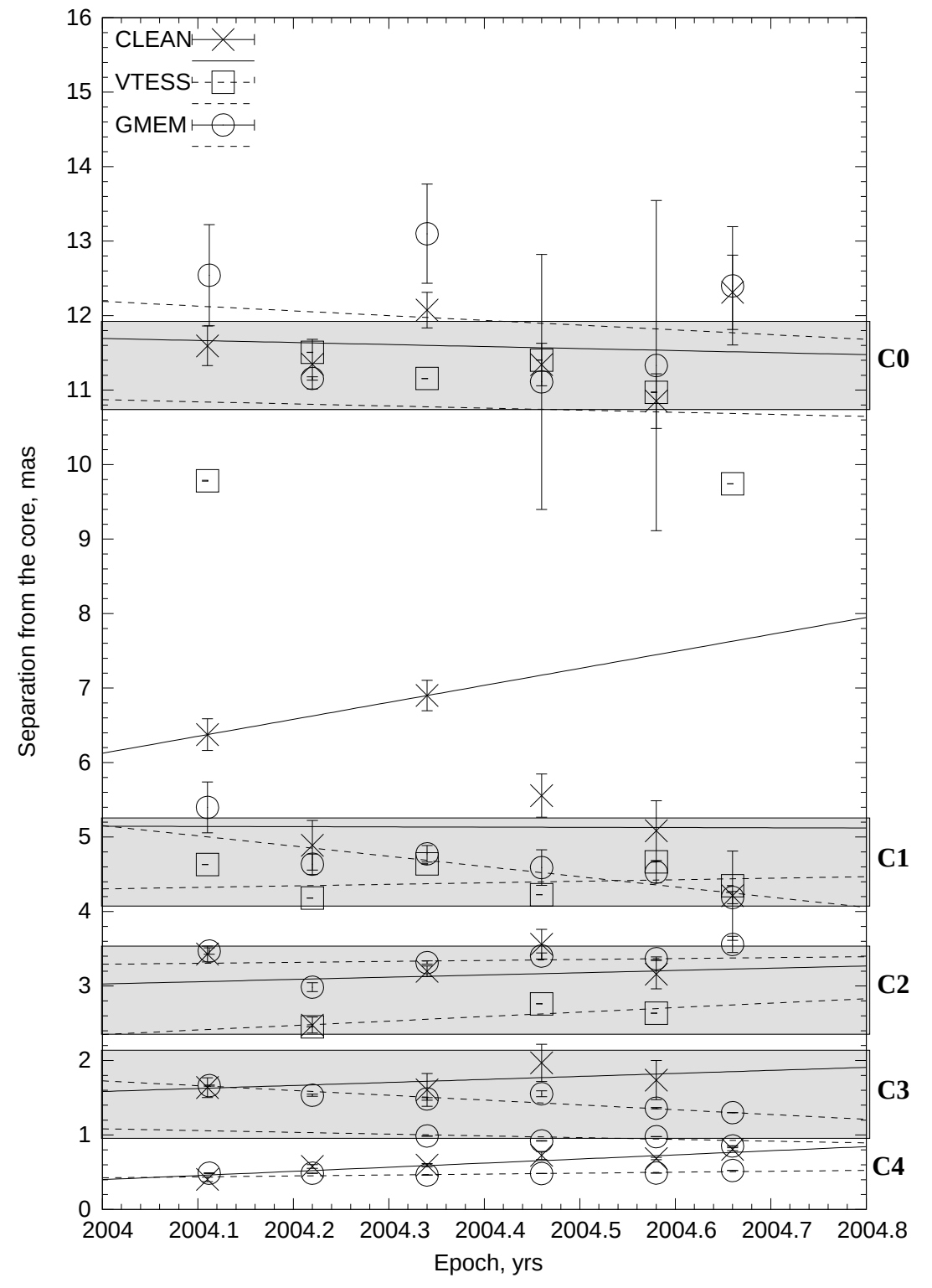

Figure 3. Combination of all three methods, discussed in Rastorgueva et al. 2010. All components, obtained with different methods, which are falling inside the same shaded area are considered to be corresponding to the same jet component.

Also we cross-identified one component (C4/KS5) between 5 and 43/22 GHz. We believe that due to the lower resolution of 5 GHz images C4/KS5 (5 GHz) is a blend of C5 and C6 (43/22 GHz) (Fig. 4).

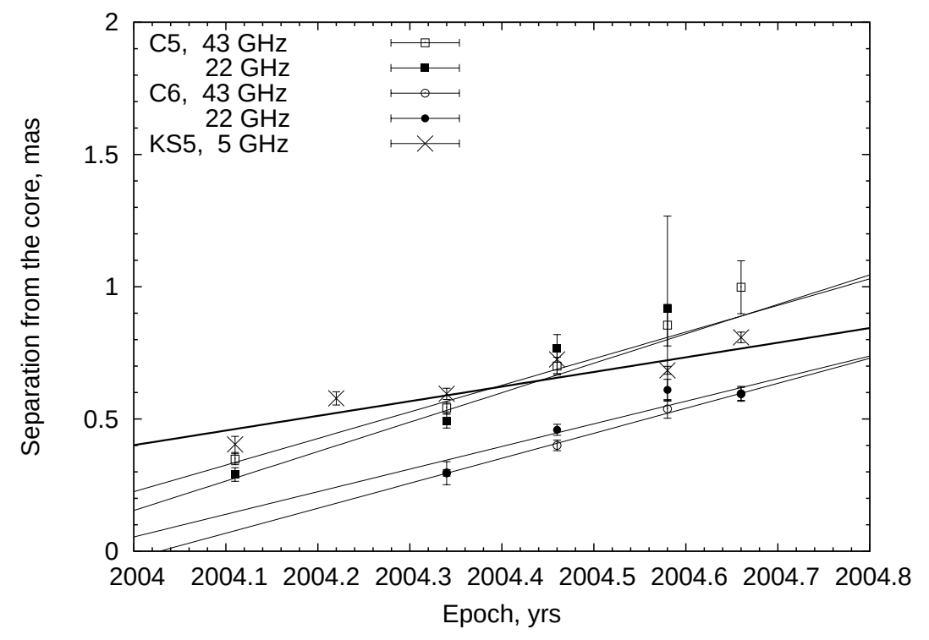

Figure 4. Component C4/KS5 at 5GHz likely corresponds to the blend of components C5 and C6 at 43/22 GHz. They are obviously located in the same area of the jet and have similar speeds.

Conclusions

In the jet of blazar 0716+714 we observe two dynamically different regions: fast inner jet (0 – 1 mas, apparent speeds up to 20c) and a stationary region (1.6 – 11.5 mas). There is a transitional area between those two regions, where components are likely decelerated. **We did not find any substantial non-radial motion of the ridge of the jet**, however, we noticed that jet slightly changes its direction, which could be seen in the Fig. 1: large-scale jet is pointing closer to the north direction than the inner one. This, together with the wiggling component motions found in the inner jet (Rastorgueva et al., 2009) and stationary nature of the large-scale, jet suggests that it has a **helical structure**. However we do not have enough data points yet to fit a helix and to determine its parameters. Future multi-frequency VLBI monitoring for a longer time and with possibly denser time coverage is needed in order to determine 3D structure of the jet of 0716+714.

Bibliography

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