Frequency-dependent core shift in ultracompact quasars

Petr Voitsik[1], Alexander Pushkarev[2,1], Yuri Kovalev[1,3,4], Alexander Plavin[1,3], Andrei Lobanov[4,5], Alexander Ipatov[6]

[1]Astro Space Center, P. N. Lebedev Physical Institute of RAS, Moscow, Russia
[2]Crimean Astrophysical Observatory, Crimea, Russia
[3]Moscow Institute of Physics and Technology, Moscow Region, Russia
[4]Max-Planck-Institut für Radioastronomie, Bonn, Germany
[5]Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany
[6]Institute of Applied Astronomy of RAS, St. Petersburg, Russia

Introduction

We present results of a pilot project to measure apparent frequency-dependent core shift effect in ultracompact quasars by the phase referencing method. A new method has been developed for measuring the core shift based on observations of close triplets of radio sources using relative astrometry. We found significant effect in 9 out of 24 targets. Mean values of the core shift for frequencies 1.7, 2.3, and 5.0 GHz relative to the highest frequency of 8.4 GHz are 1.8, 1.2, and 0.2 mas, respectively.

This work is accepted for publication in Astronomy Reports journal. Full text available on arXiv: **https://arxiv.org/abs/1809.10011**

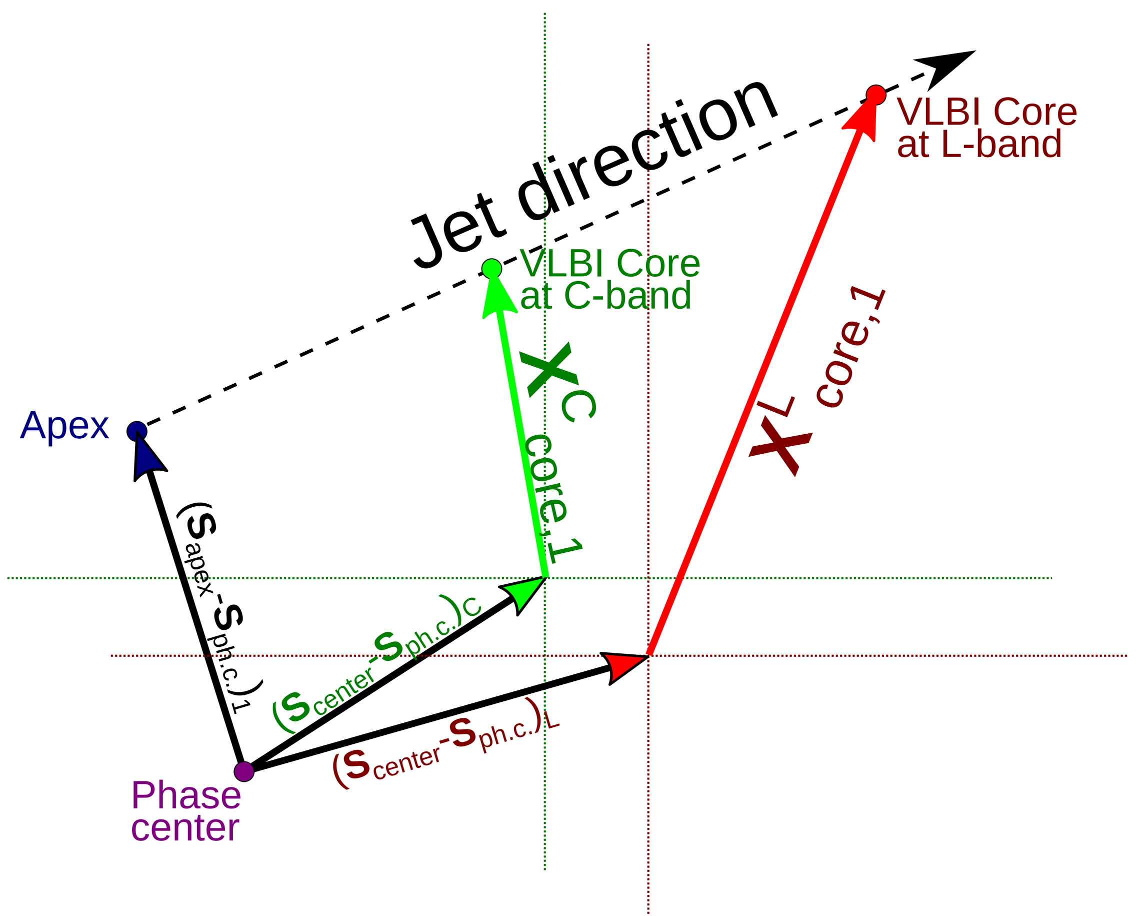
Method

It is not possible to separate the frequency-dependent core shift effect of the phase calibrator and target sources without using some additional information. Previous studies show that the VLBI core usually shifts along the relativistic jet of the source with frequency (Pushkarev et al., 2012). This makes it possible to measure the core shifts independently for each source in a triplet. We used the following model for our calculations:

$$\mathbf{X}^j_{\mathrm{core},i} = ((\mathbf{S}_{\mathrm{apex}} - \mathbf{S}_{\mathrm{ph.c.}})_i + \Delta r^j_{\mathrm{core},i}\mathbf{d}_i) - (\mathbf{S}_{\mathrm{center}} - \mathbf{S}_{\mathrm{ph.c.}})^j \,,$$

where
$i \in \{1,2,3\}$ — source number in the triplet,
$j \in \{L,S,C,X\}$ — frequency band,
$\mathbf{X}_{\mathrm{core}}$ — core position on the map,
$\mathbf{S}_{\mathrm{apex}}$ — coordinates the jet base (apex),
$\mathbf{S}_{\mathrm{ph.c.}}$ — coordinates of the phase center used in data correlation,
$\mathbf{S}_{\mathrm{center}}$ — coordinates of the map center after fringe fitting,
$\mathbf{d}$ — unit vector of jet direction,
Δr_{core} — core shift we are seeking.

Plot below shows vector diagram for one source at two frequency bands:

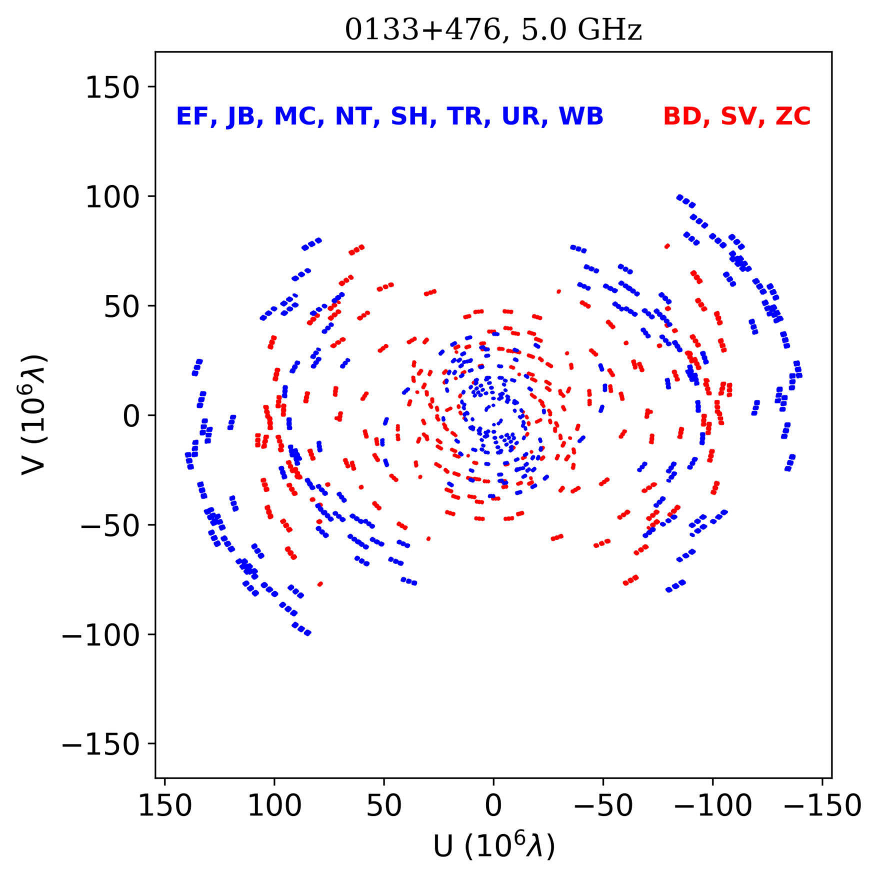


Having for a given triplet measured values of the vectors $\mathbf{X}^j_{\mathrm{core},i}$ and *a priori* estimates of the vectors $\mathbf{d}_i$, we can obtain the *a posteriori* probability density distribution of the vectors $(\mathbf{S}_{\mathrm{apex}} - \mathbf{S}_{\mathrm{ph.c.}})_i$ and $(\mathbf{S}_{\mathrm{center}} - \mathbf{S}_{\mathrm{ph.c.}})^j$, as well as the desired quantity $\Delta r^j_{\mathrm{core},i}$. We used the Markov Chain Monte Carlo method for these computations, realized in the *PyMC3* library. The core shift Δr_{core} was calculated relative to its X-band position. This approach makes it possible to estimate the core shift even if the jet direction for the source is unknown, assuming a uniform *a priori* distribution of $\mathbf{d}$.

Observations

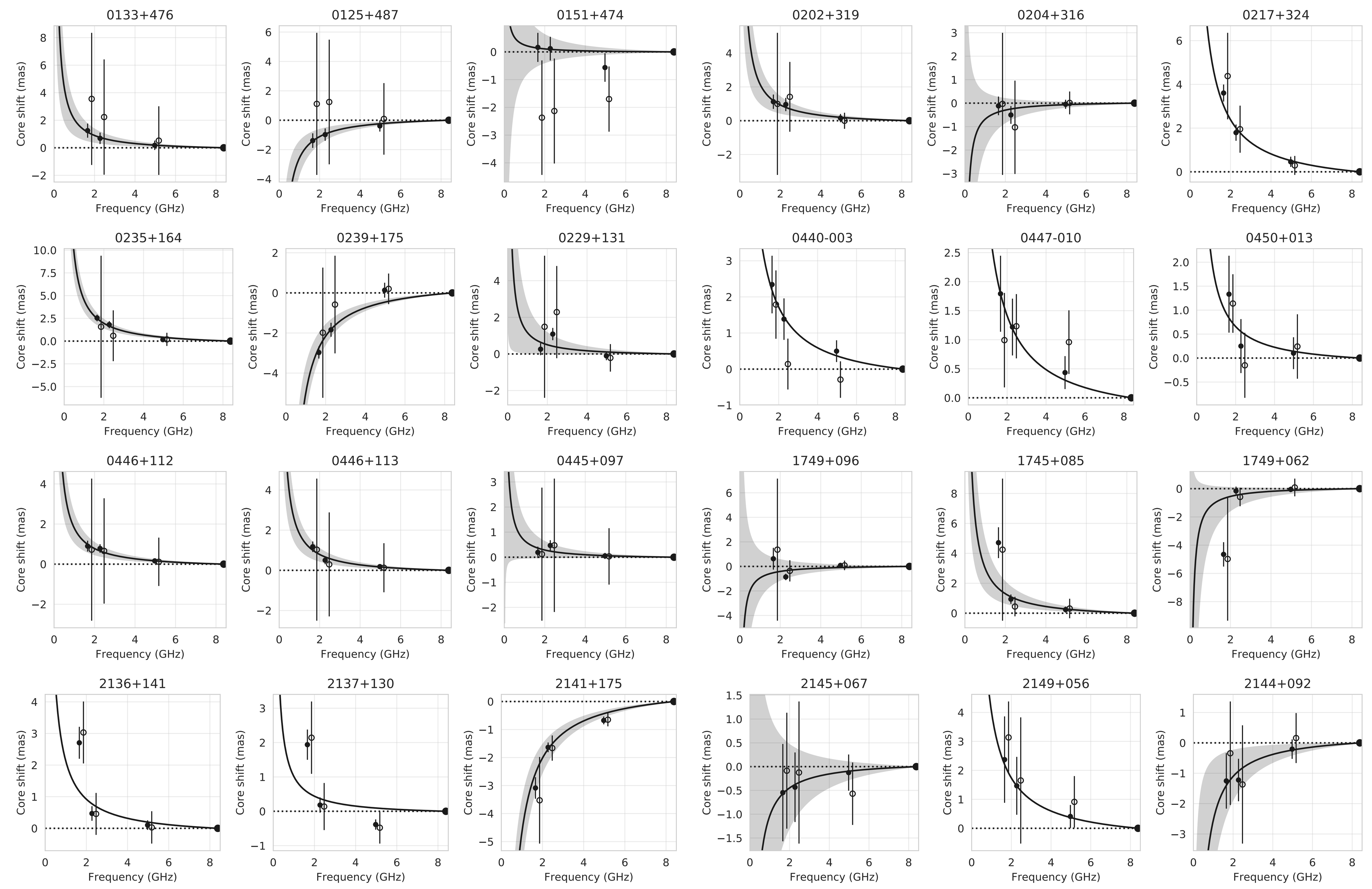
We selected 8 ultracompact extragalactic radio sources from the International Celestial Reference Frame (ICRF) catalog (Ma et al., 1998). For each of these sources, we also selected two phase calibrators at angular separations of no more than 4°.

Observations of our targets were carried out on the European VLBI Network in October 2008 at four frequenciy bands: L (1.66 GHz), S (2.27 GHz), C (4.97 GHz), and X (8.38 GHz). This experiment was the first involving three 32-m telescopes of the Russian "Kvazar-KVO" VLBI network in EVN observations. This appreciably improving the *uv*-coverage in the East–West direction. However, the failure of the Hartebeesthoek telescope in South Africa significantly limited the North–South resolution of the interferometric array.



Results of the Astrometric Core-shift measurements

The plots below show a measured frequency dependence of the VLBI core position relative to the X band. Filled circles represent the results obtained using *a priori* information of the jet directions while the hollow ones the results obtained without jet directions assumption. The curve and shaded region correspond to the dependence $\Delta r_{\mathrm{core}} = a + b/\nu$ and the 68% confidence interval.



For many sources in our sample the estimated uncertainties exceed the measured shifts. At the same time, the measured core shifts for 0133+476, 0202+319, 0217+324, 0235+164, 0440−003, 0446+112, 0446+113, 0447−010, and 2149+056 are in good agreement with the dependence $\propto \nu^{-1}$.

Conclusions

We have developed an approach to measuring the frequency-dependent core shift effect of each source in a group of closely spaced quasars, which are related by a single phase solution derived from VLBI relative astrometry. We demonstrate that this method is capable of reaching the stated goal for ultracompact sources.

Acknowledgements

This work was supported by the Russian Science Foundation (grant 16-02-10481). The European VLBI Network is a joint facility of independent European, African, Asian, and North American radio astronomy institutes. Scientific results from data presented in this publication are derived from the following EVN project code(s): EK028.