Mem. S.A.It. Vol. 79, 1153

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Physics of the central region in the quasar 0850+581

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Abstract. The apparent position of the origin (core) of extragalactic radio jets shifts with the observing frequency, owing to synchrotron self-absorption and external absorption. One of the largest core shifts was detected by us in the quasar 0850+581 between 2 and 8 GHz. We have followed this up recently by a dedicated VLBA experiment at 5, 8, 15, 24, and 43 GHz. First results from this study enabled estimating the absolute geometry and physical conditions in the parsec-scale jet origin.

Key words. galaxies: active — galaxies: jets — radio continuum: galaxies — quasars: individual (0859+581)

1. Introduction

In VLBI images of relativistic jets, the location of the narrow end of the jet (branded the "core") is fundamentally determined by absorption in the radio emitting plasma itself (synchrotron self-absorption) and/or in the material surrounding the flow (Blandford & Königl 1979; Königl 1981; Lobanov 1998) and can be further modified by strong pressure and density gradients in the flow (Lobanov 1998). At any given observing frequency, ν, the core is located in the jet region with the optical depth $\tau_s(\nu) \approx 1$, which causes its absolute position, r_c, to shift $\propto \nu^{-1/k_\mathrm{r}}$. If the core is self-absorbed and in equipartition, $k_\mathrm{r} = 1$ (Blandford & Königl 1979); k_r can be larger in the presence of external absorption or pressure/density gradients in the flow (Lobanov 1998).

Changes of the core position measured between three or more frequencies can be used for determining the value of k_r, estimating the strength of the magnetic field in the nuclear region and the offset of the observed core positions from the true base of the jet (Lobanov 1998). The power index k_r itself can vary with frequency due to pressure and density gradients or absorption in the surrounding medium, most likely, associated with the broad-line region.

If the core shifts and k_r are measured between four, or more, frequencies, the following can be addressed in detail. The magnetic field distribution can be reconstructed in the

Send offprint requests to: Y. Y. Kovalev ultra-compact region of the jet and estimates of the total (kinetic plus magnetic field) power, the synchrotron luminosity, and the maximum brightness temperature, $T_{\mathrm{b,max}}$ in the jet can be made. In addition, the ratio of particle energy and magnetic field energy can be estimated from the derived $T_{\mathrm{b,max}}$. This would enable testing the Königl (1981) model and several of its later modifications (e.g., Hutter & Mufson 1986; Bloom & Marscher 1996). The location of the central engine and the geometry of the jet can be determined. Estimation of the distance from the nucleus to the jet origin will enable constraining the self-similar jet model (Marscher 1995) and the particle-cascade model (Blandford & Levinson 1995).

In this paper we present first results of a dedicated high resolution VLBA study of the core shift effect in a central region of the distant luminous quasar 0850+581.

2. A large core shift in the quasar 0850+581

We have imaged the NRAO archival data and used results of the VLBA S/X project BF 025 to estimate core shifts in a number of sources (see description of the BF 025 program in Fey & Charlot 2000). We have found an intriguing case of the distant quasar 0850+581 (redshift $z = 1.318$, SDSS release 2) for which the core shift was estimated to be 1.5 mas between 2.3 and 8.6 GHz (Kovalev et al. 2008). The total error of the core shift value for this object is dominated by blending of the first bright jet component with the core at long wavelengths. However, the distance between the core and this component was about 0.5 mas. This means that the huge core shift value about 1 mas measured between 2.3 and 8.6 GHz and 2.3 and 15 GHz must be real.

So far, this is one of the largest core shifts detected. This object is particularly suited for VLBI observations at high radio frequencies because of the bright component located close to the core (see Figure 1). We observed this source in a dedicated 5–43 GHz VLBA experiment to confirm the core shift and study physics of the nuclear region in this quasar.

3. 5-43 GHz VLBA observations and core shift measurements results

We performed VLBA observations of the quasar 0850+581 at 5, 8, 15, 24, & 43 GHz frequency bands during 15 hours on February 17, 2008 (project code BK 142). This was done as a phase referencing experiment, which includes a phase calibrator selected from the VLBA Calibrator Survey (e.g., Petrov et al. 2008) allowing to do differential astrometry measurements. Imaging results at four bands with comparable dynamic range are presented in Figure 1.

First results of the core-shift measurements are presented in Figure 2. They include one data point at 2.3 GHz, which is an extrapolation from previous measurements (Kovalev et al. 2008). It should be noted that these results are achieved using the self-referencing alignment method and spectral index analysis (see for details Kovalev et al. 2008). We plan to perform a differential astrometry analysis at a later point and present results elsewhere.

4. Physical properties of the jet origin

We did not detect significant deviation of k_{r} from unity (Figure 2), which mean that the shift happens purely as a result of synchrotron self-absorption. External absorption is not significant at the observed core positions at least until 24 GHz.

We apply the method suggested by Lobanov (1998) and assume the following parameters for the jet of 0850+581: Lorentz factor $\Gamma = 10$ (from kinematics measurements by Kellermann et al. 2004), viewing angle 10° (from the two-sided kiloparsec scale morphology by Reid et al. 1995), jet opening angle $1/\Gamma^2 = 0.6°$. The following parameters were estimated. Distance from the observed core to the central supermassive black hole is found to differ from 17 pc (at 5 GHz) to 5 pc (at 24 GHz). Magnetic field strength at a distance of 1 pc from the nucleus is $B = 3.1 \pm 0.2$ G (for assumed particle density 1000 cm^{-3}), which is consistent with equipartition magnetic field ($B = 2.7 \pm 0.7$ G). Magnetic field strength at

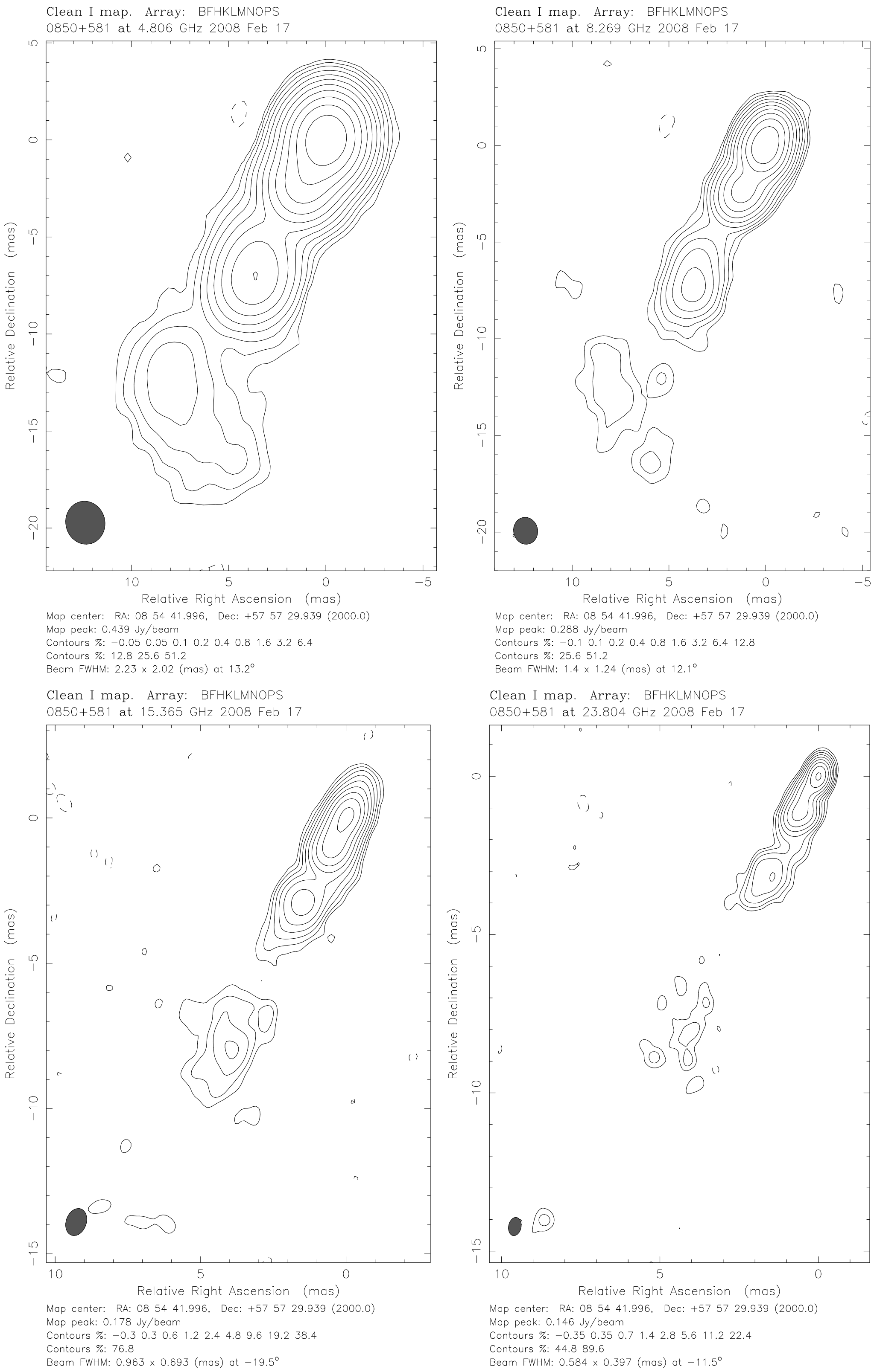

Fig. 1. Stokes I contour CLEAN maps of the quasar 0850+581 observed quasi-simultaneously by VLBA on February 17, 2008. Images are restored with natural weighting. One milliarcsecond is about 8.4 pc.

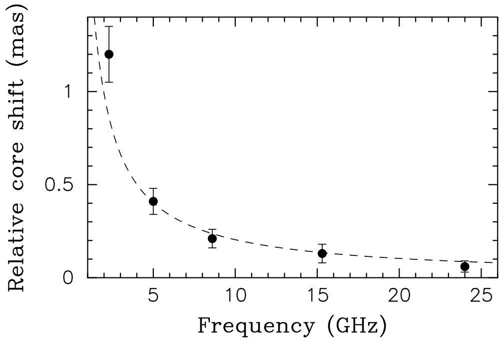

Fig. 2. Frequency dependence of the core shift value measured relative to the core position at 43 GHz. The curve represents the best fit for the function $r_c \propto \nu^{-k_r}$, where $k_r = 1.1 \pm 0.1$.

the position of the apparent 24 GHz core is $B = 0.2 \pm 0.4$ G.

5. Summary

The nuclear opacity in relativistic jets significantly affects observed positions of compact radio cores. This effect provides an efficient tool to study physics of compact jet nuclei. Application of this to the quasar 0850+581 with a large core shift effect allowed to determine geometry and physics in the inner region of compact jet.

The distant quasar 0850+581 is an ICRF source (Ma et al. 1998) and is monitored in astrometric/geodetic VLBI sessions. Results of this study can be used to improving the absolute position of the object and for aligning positions measured at different observing bands.

Acknowledgements. The National Radio Astronomy Observatory is a facility of the National Science Foundation operated under cooperative agreement by Associated Universities, Inc. We thank D. Vir Lal for careful reading the manuscript and useful comments. Y. Y. Kovalev is a Research Fellow of the Alexander von Humboldt Foundation. Y. Y. Kovalev was supported in part by the Russian Foundation for Basic Research (project 05-02-17377, 08-02-00545). This research has made use of NASA's Astrophysics Data System and the NASA/IPAC Extragalactic Database (NED) which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.

References

Blandford, R. D. & Königl, A. 1979, ApJ, 232, 34
Blandford, R. D. & Levinson, A. 1995, ApJ, 441, 79
Bloom, S. D. & Marscher, A. P. 1996, ApJ, 461, 657
Fey, A. L. & Charlot, P. 2000, ApJS, 128, 17
Hutter, D. J. & Mufson, S. L. 1986, ApJ, 301, 50
Kellermann, K. I., Lister, M. L., Homan, D. C., et al. 2004, ApJ, 609, 539
Königl, A. 1981, ApJ, 243, 700
Kovalev, Y. Y., Lobanov, A. P., Pushkarev, A. B., & Zensus, J. A. 2008, A&A, 483, 759
Lobanov, A. P. 1998, A&A, 330, 79
Ma, C., Arias, E. F., Eubanks, T. M., et al. 1998, AJ, 116, 516
Marscher, A. P. 1995, Proceedings of the National Academy of Science, 92, 11439
Petrov, L., Kovalev, Y. Y., Fomalont, E. B., & Gordon, D. 2008, AJ, 136, 580
Reid, A., Shone, D. L., Akujor, C. E., et al. 1995, A&AS, 110, 213