Future Directions in High Resolution Astronomy: The 10th Anniversary of the VLBA
ASP Conference Series, Vol. 340, 2005
J. D. Romney and M. J. Reid (eds.)

Extragalactic Radio Source Spectra and Structure: RATAN–600 and VLBA Observations

Yuri Y. Kovalev

National Radio Astronomy Observatory, P.O. Box 2, Green Bank, WV 24944, USA and
Astro Space Center of Lebedev Physical Institute, Moscow, Russia

Yuri A. Kovalev

Astro Space Center of Lebedev Physical Institute, Profsoyuznaya 84/32, 117997 Moscow, Russia

Nikolai A. Nizhelsky

Special Astrophysical Observatory, Nizhniy Arkhyz, Karachaevo–Cherkessiya, 369167 Russia

1. Observations

Broad-band spectra observations were made at 31, 13, 7.7, 3.9, 2.7, and 1.4 cm, simultaneously for all frequencies, with the 600 meter ring radio telescope RATAN in the framework of a long-term monitoring program. Results of observations made in 1997, December, list of the sources included in the monitoring, description of a method of observations and data processing are presented in Kovalev et al. (1999). Horizontal localization of the stationary antenna feed horns allows broad-band spectral responses to be obtained at all observed frequencies during 1–2 minutes in the transit mode of meridional observations. In this work we have used monitoring data from 1994 to 2002 for about 160 quasars and active galactic nuclei. VLBA data is obtained in the 2 cm VLBA monitoring program (see for details Kellermann et al. 1998, Zensus et al. 2002, as well as http://www.cv.nrao.edu/2cmsurvey/). RATAN–600 instantaneous spectra and VLBA 2 cm images for all the program sources may be found at the web site.

2. Variable Radio Spectra

From statistical and numerical model analysis of observed spectra we conclude that the spectra can be modeled as the sum of a synchrotron spectrum of an extended optically thin component (magnetized envelope/lobe, 'spectrum 1'), dominating at lower frequencies, and a synchrotron spectrum of a compact component (relativistic jet, 'spectrum 2'), dominating at higher frequencies. Spectrum 1 is generally constant or weakly variable, spectrum 2 can exhibit any degree of variability (Kovalev et al. 2002). Considering non-stationary jets, a combination of two spectral components can explain features of spectra with complex shapes. Variable emission of a jet can be produced by the non-stationary outflow of relativistic particles in the longitudinal magnetic field

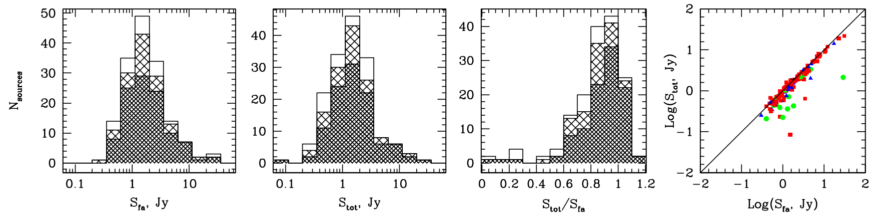

Figure 1. Source distributions on 15 GHz flux densities $S_{\rm fa}$ (RATAN), $S_{\rm tot}$ (VLBA total CLEAN), index of compactness $S_{\rm tot}/S_{\rm fa}$, and $S_{\rm tot}$–$S_{\rm fa}$ dependence. In histograms we separate quasars (most hatched area) from BL Lacs (medium hatched) and active galaxies (empty).

(see, e.g., Kovalev et al. 2000) or by the propagation of relativistic shocks (see, e.g., Marscher & Gear 1985).

Factors of centimeter flux density variations range between 1 and 15. Typical evolution of a broad-band radio spectrum during strong outburst is recognized: a wave of a perturbation moves along the spectrum from higher to lower frequencies. Quasars and BL Lacertae objects have similar fashion and rate of long-term variability. Therefore, the hypothesis of the same physical nature of flares in quasars and BL Lacs is supported.

3. Comparison with the VLBA Data

Figure 1 presents distributions of the filled aperture $S_{\rm fa}$ (RATAN) and VLBA CLEAN total $S_{\rm tot}$ flux densities and their ratio (or "index of compactness"). The good agreement between $S_{\rm tot}$ and $S_{\rm fa}$ indicates that for most sources of the sample the VLBA sees nearly total flux density, and that there are no significant systematic errors in the flux density scale of the VLBA. Aside from the few sources that clearly have large scale structure, the mean compactness index $< S_{\rm tot}/S_{\rm fa} >$ for the sample is about 0.86. Several objects have compactness index $S_{\rm tot}/S_{\rm fa} > 1$; this is most likely due to source variability and non-simultaneity of the VLBA and filled aperture observations. Sources with the compactness index $S_{\rm tot}/S_{\rm fa}$ close to 1 at all epochs are suitable for calibration of other centimeter VLBI experiments.

The peak of $S_{\rm fa}$ distribution corresponds to the selection limit of the sample. The peak position and the shape of the left wing reflect the discrepancy between the actual 15 GHz flux density and the value extrapolated by Kellermann et al. (1998) and Zensus et al. (2002), largely due to the variability of the sources.

On modeling the broad-band radio spectra of compact extragalactic radio sources, we derived that a compact relativistic jet must be responsible for the centimeter and millimeter part of the spectrum. This inference is also supported by the compactness analysis. Consequently, a correlation of long term variability between $S_{\rm tot}$ and $S_{\rm fa}$ is anticipated. We have checked and confirmed its presence. These results support our previous interpretation of (i) quiescent spectra by the emission of a jet in a quasi-stationary phase and (ii) the spectra variability at frequencies higher than 1–3 GHz by the strongly variable spectrum 2.

Radio sources with average 11–22 GHz two-point spectral index $\alpha > -0.5$ ($S_\nu \sim \nu^\alpha$) display VLBI jet component motions with speeds in the range from 0 to more than $30\,c$, while for sources with steeper spectra speeds not more than $6\,c$ are observed (see for details Kellermann et al., in preparation).

4. Summary

We have used the RATAN 600 meter ring transit radio telescope near Zelenchukskaya, Russia, to observe time variations of broad-band radio spectra of quasars and AGN at six frequencies over the range from 1 to 22 GHz. The RATAN data, which covers the period 1995–2003 with 2 to 4 observations per year, have been compared with 15 GHz VLBA observations of the milliarcsecond source structure. Many sources show pronounced spectral variability with observed flux density changes of up to an order of magnitude over a period of a few years. Observations made only a few years apart often show very different types of spectra. Comparison of the VLBA images with the total power RATAN data indicates that typically from 70% to 100% of the total flux density is contained in the VLBA image. Most spectra are dominated by a single high frequency component which is thought to be a compact relativistic jet.

Acknowledgments. This paper is based in part on work done in collaboration with M. H. Cohen, D. C. Homan, K. I. Kellermann, M. L. Lister, E. Ros, R. C. Vermeulen, and J. A. Zensus. YYK is a Jansky postdoctoral fellow of the NRAO. This research has been partly supported by the NASA JURRISS program (W–19611), the Russian Foundation for Basic Research (projects 01–02–16812, 02–02–16305), and the Russian State Program "Astronomy". The NRAO is a facility of the NSF operated under cooperative agreement by Associated Universities, Inc.

References

Kellermann, K. I., Vermeulen, R. C., Zensus, J. A., & Cohen, M. H. 1998, AJ, 115, 1295

Kovalev, Y. Y., Nizhelsky, N. A., Kovalev, Yu. A., Berlin, A. B., Zhekanis, G. V., Mingaliev, M. G., & Bogdantsov, A. V., 1999, A&AS, 139, 545

Kovalev, Yu. A., Kovalev, Y. Y., & Nizhelsky, N. A. 2000, PASJ, 52, 1027

Kovalev, Y. Y., Kovalev, Yu. A., Nizhelsky, N. A., & Bogdantsov, A. B., 2002, PASA, 19, 83

Marscher, A. P., & Gear W. K., 1985, ApJ, 298, 114

Zensus, J. A., Ros, E., Kellermann, K. I., Cohen, M. H., Vermeulen, R. C., & Kadler, M., 2002, AJ, 124, 662