ВАК 2024
MODERN ASTRONOMY:
FROM THE EARLY UNIVERSE TO EXOPLANETS AND BLACK HOLES
300 years Russian Academy of Sciences

Search for proton jets in blasars as possible emitters of high-energy neutrinos

Yu. A. Kovalev[1,2], G. Zhekanis[3], Yu. Yu. Kovalev[4], Yu. Sotnikova[3], S. Troitsky[2], A. Popkov[1,5], A. Plavin[6], A. Erkenov[3], M. Mingaliev[3], N. Nizhelsky[3], P. Tsybulev[3], and N. Bursov[3]

[1] Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, 117997 Russia
[2] Institute for Nuclear Research of the Russian Academy of Sciences, Moscow, 117312 Russia
[3] Special Astrophysical Observatory of the Russian Academy of Sciences, Nizhny Arkhyz, 369167 Russia
[4] Max Planck Institute for Radio Astronomy, Bonn, 53121 Germany
[5] Moscow Institute of Physics and Technology, Dolgoprudny, 141700 Russia
[6] Black Hole Initiative at Harvard University, Cambridge, MA 02138 USA

Abstract. We continue the RATAN-600 observations of instantaneous 1–22 GHz spectra of active galactic nuclei at 5–7 frequencies in 1997–2024. The main task is the analysis of the results including the CATS database for data beyond 1–22 GHz and the Hedgehog model proposed by N. S. Kardashev in 1969. The new goal is to study the physical parameters of jets in VLBI-blazars and search for compact bright strong variable proton jets as possible sources of high-energy neutrinos in proton-proton and proton-photon processes. Main results of estimating values for magnetic fields, brightness temperatures and angular sizes of both proton and electron jets in 9 blasars are presented. This allows to explain the RadioAstron extra-high brightness temperatures and magnetic fields as well as extremely compact cores in radio jets and to link proton sources of high-energy neutrinos with some radio jets.

Keywords: galaxies: active, jets; neutrinos; magnetic fields

DOI: 10.26119/VAK2024.012

1 Introduction

Analysis of extragalactic possible "radio-neutrino" sources leads to the preliminary hypothesis that their main properties may be the following (Troitsky 2021; Kovalev et al. 2022): 1) long-term wide-range variability of radio emission with strong (including repeated) flow bursts up to 10–20 times in amplitude and quasiperiods up to tens of years in the cm and mm ranges; 2) maximum brightnesses, close to the RadioAstron extremely high, and minimum angular size, close to extremely small; 3) two parts of the proton energy distribution – with high energies $E_p > 500$ TeV (in order to participate in the birth of neutrinos with energies $E_\nu > 25$ TeV) and with E_p up to 1 TeV (in order to generate the jet radio emission). It was previously shown that the radio emission from variable extragalactic objects can be described by synchrotron radiation of electrons or protons in a strong quasi-radial magnetic field of a relativistic jet in the Hedgehog model proposed by N. S. Kardashev in 1969 and developed later by a number of authors (Kovalev et al. 2000).

2 Observation, analysis and results

The report summarizes previous results and continues the model analysis of the main physical parameters for quasars and galaxies – from their subsample with the strongest long-term variability of radiation as measured by RATAN-600. For B0235+16, a repetition of spectrum changes was discovered for the first time during a strong burst in the range 1–22 GHz – after 22 years. The results of RATAN-600 measurements of instantaneous radio spectra at 1–22 GHz in 1997–2024 (Kovalev et al. 2022), and the data outside this range from the CATS database (Verkhodanov et al. 2005) were used. Using these data and the Hedgehog jet model, estimates of the physical parameters for electron and proton jets were obtained – magnetic field, brightness temperature, angular size (similar to Sotnikova et al. 2022). The results of fits and estimations are shown in Fig. 1 and in Table 1 and do not contradict VLBI/RadioAstron measurements (see Kovalev et al. 2020). For the sake of simplicity, the red shift is still neglected and it is assumed that for all the objects under consideration, the parameter $\gamma_E = E/(M \cdot c^2) \sim 300$ at the frequency ν_m of the jet spectrum maximum, where E is the energy and M is the mass of emitted electrons or protons (see also Sotnikova et al. 2022). Protons for the radio emission and for the production of neutrinos may be accreted from the disk and accelerated to the required energy distribution (including the Faraday induction mechanism) in a region with a strong magnetic field in the vicinity of the SMBH or, in addition, could be accelerated during bursts due to precessing binary black holes that occasionally cross the accretion disk similar to Ivanov & Zhuravlev (2024).

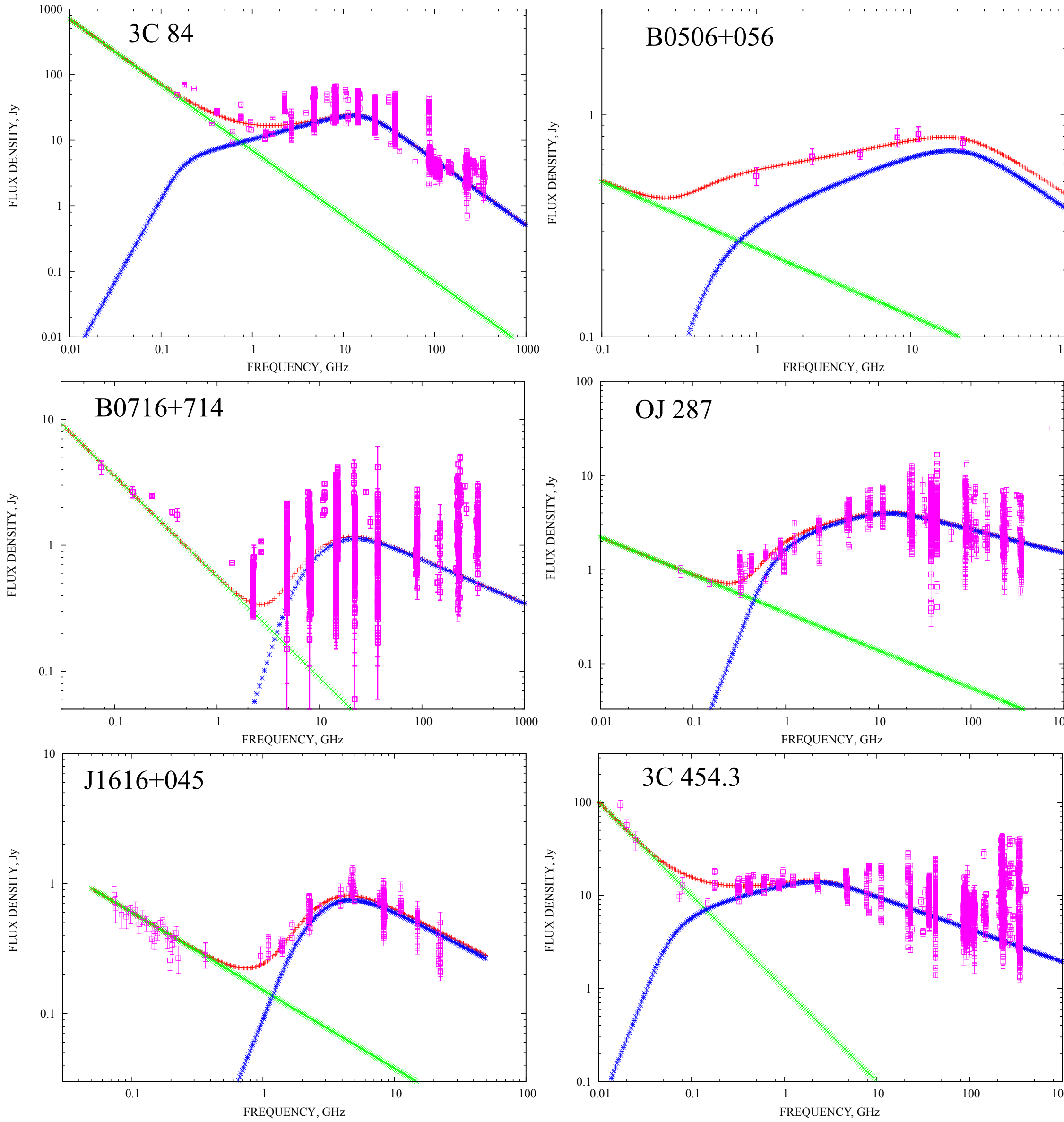

Fig. 1. Results of fitting the Hedgehog model (Kovalev et al. 2000) to the mean 0.01–500 GHz spectra of observed flux density in Jy for 6 examples of 9 AGNs in Table 1. The sum of two spectral model components have been fitted. The High Frequency Component (HFC, a curve spectrum of the jet) is variable, it is emitted by the relativistic jet in the strong quasi-radial magnetic field. The Low Frequency Component (LFC – a line spectrum) is practically non-variable and is emitted by the other parts of the source. The 1–22 GHz data are the RATAN-600 data, in general. The data at other frequencies and partly at 1–22 GHz were taken from the CATS data base (Verkhodanov et al. 2005). Fitting for B0506+056 is shown for the instantaneous spectrum on the RATAN-600 data only; more data for it see in the paper by Baikal-GVD collaboration et al. (2024).

Table 1. Results of the model fitting the magnetic field B, brightness temperature T_b and angular size Θ of the jets near the maximum of the spectra. The equracy is of the order of the values.

Object	Particles	B Gauss	T_b K	Θ mas	References
+3C 84	electrons	9	$5 \cdot 10^{10}$	1	
	protons	$2 \cdot 10^4$	$9 \cdot 10^{13}$	0.03	
+B0506+056	electrons	6	$5 \cdot 10^{10}$	0.1	
	protons	$1 \cdot 10^4$	$9 \cdot 10^{13}$	0.003	
S5 0716+71	electrons	0.5	$5 \cdot 10^{10}$	1.5	
	protons	900	$9 \cdot 10^{13}$	0.03	
+OJ287	electrons	5	$5 \cdot 10^{10}$	0.3	
	protons	$8 \cdot 10^3$	$9 \cdot 10^{13}$	0.007	
+3C279	electrons	15	$5 \cdot 10^{10}$	3	
	protons	$3 \cdot 10^4$	$9 \cdot 10^{13}$	0.07	
+B1502+10	electrons	7	$5 \cdot 10^{10}$	0.6	Sotnikova et al. (2022)
	protons	$1 \cdot 10^4$	$9 \cdot 10^{13}$	0.014	
+J1616+04	electrons	0.15	$5 \cdot 10^{10}$	0.1	
	protons	300	$9 \cdot 10^{13}$	0.002	
+3C 454.3	electrons	2	$5 \cdot 10^{10}$	4	
	protons	$4 \cdot 10^3$	$9 \cdot 10^{13}$	0.08	
+0954+658	electrons	20	$5 \cdot 10^{10}$	0.08	Vlasyuk et al. (2023)
	protons	$4 \cdot 10^4$	$9 \cdot 10^{13}$	0.002	

Acknowledgements. The observations were carried out with the RATAN-600 scientific facility. The work is supported in the framework of the State project "Science" by the Ministry of Science and Higher Education of the Russian Federation under the contract 075-15-2024-541.

References

Baikal-GVD collaboration et al., 2024, MNRAS, 527, p. 8784
Ivanov P. and Zhuravlev V., 2024, MNRAS, 528, p. 337
Kovalev Yu. Yu., Kardashev N., Sokolovsky K., et al., 2020, Adv.Sp.Rec., 65, p. 705
Kovalev Yu. A., Kovalev Yu. Yu., and Nizhelsky N., 2000, PASJ, 52, p. 1027
Kovalev Yu. A., Nizhelsky N., Kovalev Yu. Yu., et al., 2022, Proceedings of Science, 425, id. 27
Sotnikova Yu., Kovalev Yu. A., Kovalev Yu. Yu., et al., 2022, Proceedings of Science, 399, id. 9
Troitsky S., 2021, Physics-Uspekhi, 64, p. 1261
Verkhodanov O., Trushkin S., Andernach H., and Chernenkov V., 2005, Bull.SAO, 58, p. 118
Vlasyuk V., Sotnikova Yu., Volvach A., et al., 2023, Astrophys. Bulletin, 78, p. 464