RELATIONS OF RADIO SOURCES WITH JETS PARAMETERS

A. P. Miroshnichenko

Institute of Radio Astronomy, NAS of Ukraine
4 Chervonopraporna Str., Kharkiv, Ukraine
e-mail: mir@ira.kharkov.ua

We considered the sample of galaxies and quasars with jets based on observed data. We obtained the magnetic field strength in these objects using the condition of energy equipartition between the relativistic particles and the magnetic field. We determined values of luminosities in the radio band and in optics. The relations of the sample object radio sizes, luminosities, spectral indices, redshift were derived. An estimations of the lifetime for objects with jets were obtained too.

INTRODUCTION

It is known that the physical nature of the nuclei activity of galaxies and quasars is not determined finally. So, the studies of different physical parameters of these objects are actual and needed for correct theoretical models of radio sources and for interpretation of observed data. It is important to examine the jet objects.

Jets are the typical features of ~70% of radio galaxies and ~50% of quasars. They contain the relativistic particles, thermal plasma and magnetic field.

According to modern ideas jets, *i.e.*, collimated beams flowing from active nuclei are responsible for observed radio structure of objects.

SAMPLE DESCRIPTION

We considered the sample of jet objects from observed data [3, 5–7]. We also used the data according to the sample objects at the optical and decametric band [1, 2, 8].

Our sample consists of 132 radio sources with jets, including 76 galaxies and 56 quasars. The mean sample redshift value is 0.066 ± 0.012 for galaxies, and 0.982 ± 0.084 for quasars. On the whole for our sample the mean redshift value is 0.510 ± 0.063. The mean spectral index has value $\langle a \rangle = 0.75 \pm 0.04$ for objects with redshift $z \leq \langle z \rangle$ and $\langle a \rangle = 0.64 \pm 0.06$ for objects with redshift $z > \langle z \rangle$.

THE DETERMINATION OF PHYSICAL PARAMETERS OF JET OBJECTS

At accounts of physical parameters of objects we suppose the synchrotron mechanism of generation of optical and radio radiation of active nuclei. In this paper the flat model of the Universe with parameter $q_0 = 0.5$ and the Hubble constant $H_0 = 100$ km/s Mpc is used. As jets are well collimated flows, we consider that the losses of energy of relativistic electrons on adiabatic expansion of a jet are insignificant in relation to losses of their energy on synchrotron radiation. The jets can be kept from expansion both external pressure, and own magnetic field.

For definition of a magnetic field strength of radio sources we accept a hypothesis about equipartition of magnetic field energy and energy of relativistic particles. Under such condition of the magnetic field strength of a radio source we find from the ratio [4]:

$$B = \left[48kA(\gamma, \nu) \frac{S_\nu}{r\varphi^3} \right]^{2/7}, \tag{1}$$

where $k = 100$ (proton to electron energy ratio); $A(\gamma, \nu)$ is the tabular function; γ is the index of the electron energy distribution; S_ν is the flux density with respect to frequency; r is the jet distance; φ is the jet angular dimension.

The determined values B range from $\sim 10^{-2}$ to 10^{-5} G that corresponds to known data. The mean value of the magnetic field strength is $\langle B_G \rangle = 1.37\,(\pm 0.99) \cdot 10^{-4}$ G for galaxies and $\langle B_G \rangle = 1.6\,(\pm 1.2) \cdot 10^{-3}$ G for quasars. We estimated values of minimal total energy

$$E^{\min} = E_{rel} + E_B = \frac{7}{4}\,(1+k)\,A(\gamma,\nu)\,r^2\,\frac{S_\nu}{B^{3/2}} \qquad (2)$$

and total luminosities for jet objects by using values of magnetic field strength

$$L_{tot} = c\pi R^2 B^2. \qquad (3)$$

These values are $\langle E^{\min}\rangle_G = 3.77\,(\pm 1.65)\cdot 10^{60}$ erg, $\langle L_{tot}\rangle_G = 5.68\,(\pm 3.23)\cdot 10^{48}$ erg/s, $\langle E^{\min}\rangle_Q = 7.14\,(\pm 2.45)\cdot 10^{60}$ erg, $\langle L_{tot}\rangle_Q = 1.03\,(\pm 0.16)\cdot 10^{49}$ erg/s for galaxies and quasars, respectively.

We also derived the characteristic size of radio structure (mean value of object radii) $\langle R\rangle_G = 2.54\,(\pm 0.77)\cdot 10^{23}$ cm, $\langle R\rangle_Q = 2.07\,(\pm 0.34)\cdot 10^{23}$ cm for galaxies and quasars, respectively.

We considered that the active nuclei luminosity of jet sources L_{tot} is near the critical luminosity value

$$L_{edd} = 1.2\cdot 10^{38}\,\frac{M}{M_\odot}, \qquad (4)$$

which corresponds to Eddington limit for given mass. From this ratio we estimated object masses $\langle M_G\rangle = 9.46\,(\pm 5.38)\cdot 10^{43}$ g, $\langle M_Q\rangle = 1.71\,(\pm 0.26)\cdot 10^{43}$ g for galaxies and quasars, respectively.

Based on our data we calculated the characteristic time of the synchrotron decay of relativistic electrons in jet sources:

$$t_B = \left(\frac{340 B^{-3}}{\nu}\right)^{1/2}, \qquad (5)$$

where t_B is in years, B is in Gauss, ν is in MHz. This value is $\langle t_b\rangle_G = 4.39\,(\pm 1.84)\cdot 10^6$ yr for galaxies and $\langle t_b\rangle_Q = 1.44\,(\pm 0.41)\cdot 10^6$ yr for quasars at the centimeter band. For the decametric band these estimates are increase to one order, that is $\langle t_B\rangle_G \sim 5\cdot 10^7$ yr, $\langle t_B\rangle_Q \sim 10^7$ yr.

From the other side, we derived the minimal source age t_L as

$$t_L = \frac{E^{\min}}{L_{tot}}, \qquad (6)$$

and it is $\langle t_L\rangle_G = 7.47\,(\pm 2.26)\cdot 10^{11}$ s, $\langle t_L\rangle_Q = 6.09\,(\pm 1.01)\cdot 10^{11}$ s.

To estimate the velocity of jet propagation we used both the value t_L and the source radius:

$$v = \frac{R}{t_L}. \qquad (7)$$

For our sample we derived the sublight velocities of jet propagation which indicate the dependence from redshift:
$\langle v\rangle_G = 4.98\,(\pm 2.14)\cdot 10^9$ cm/s, $\langle z\rangle_G = 0.07$; $\langle v\rangle_Q = 1.99\,(\pm 0.71)\cdot 10^{10}$ cm/s, $\langle z\rangle_Q = 0.98$.

Supposing that object luminosity L_{tot} is due to matter flowing, we obtained the mean rate of matter flowing $\frac{dM}{dt}$ for galaxies and quasars by the relation:

$$L_{tot} = \frac{1}{2}\frac{dM}{dt}v^2. \qquad (8)$$

Then, the values $\left\langle \frac{dM}{dt}\right\rangle$ are the next: $\left\langle \frac{dM}{dt}\right\rangle_G = 7.30\,(\pm 2.14)\cdot 10^{29}$ g/s and $\left\langle \frac{dM}{dt}\right\rangle_Q = 3.38\,(\pm 0.66)\cdot 10^{29}$ g/s for galaxies and quasars. So, we obtained the additional estimate of the jet object age:

$$t_M = \frac{M}{\frac{dM}{dt}} \qquad (9)$$

with values $\langle t_M\rangle_G = 6.63\,(\pm 5.27)\cdot 10^{14}$ s and $\langle t_M\rangle_Q = 2.60\,(\pm 0.96)\cdot 10^{15}$ s for galaxies and quasars.

We also calculated the ratios of the monochromatic luminosities of jet objects at 25 MHz, 5 GHz, and in optics. Note that these are independent from the Universe model. We also derived luminosity ratio values such as: $\left\langle \log\left(\frac{L_{25}}{L_{opt}}\right)\right\rangle_G = 4.40 \pm 0.20$; $\left\langle \log\left(\frac{L_5}{L_{opt}}\right)\right\rangle_G = 2.77 \pm 0.13$ for galaxies and $\left\langle \log\left(\frac{L_{25}}{L_{opt}}\right)\right\rangle_Q = 5.11 \pm 0.14$; $\left\langle \log\left(\frac{L_5}{L_{opt}}\right)\right\rangle_Q = 3.48 \pm 0.09$ for quasars.

ANALYSIS OF PARAMETER RELATIONS OF THE JET SOURCES

We have considered the relations between the magnetic field strength and the redshift and the spectral index, indicating a large dispersion of these values for jet objects. An analogous character has the relation between the object linear size and the spectral index and the redshift.

The dependence of jet velocity on the redshift indicates the correlation of these parameters (Fig. 1).

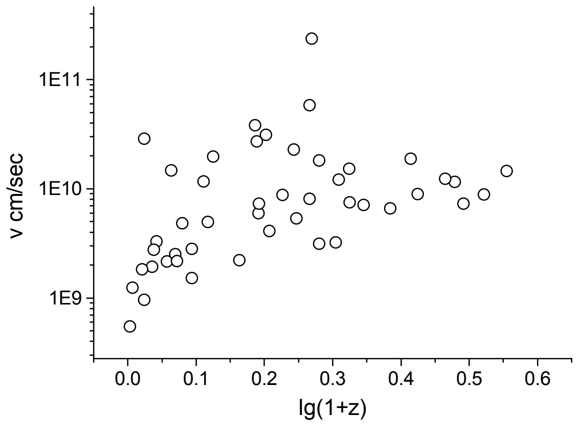

Figure 1. The jet propagation velocity against the redshift for jet objects

It is interesting to study the luminosity ratio of objects at different frequency bands due to its independence from the Universe model. For galaxies and quasars in our sample we derived the evolution trend of luminosity ratio for decametric and optical bands (Fig. 2), and for centimeter and optical bands (Fig. 3). Note that these relations indicate the smaller dispersion for the first case (see Fig. 2). This corresponds the synchrotron mechanism of the object radiation, when the radio sources evolve more rapidly at more higher frequencies evidently indicating the cosmological evolution.

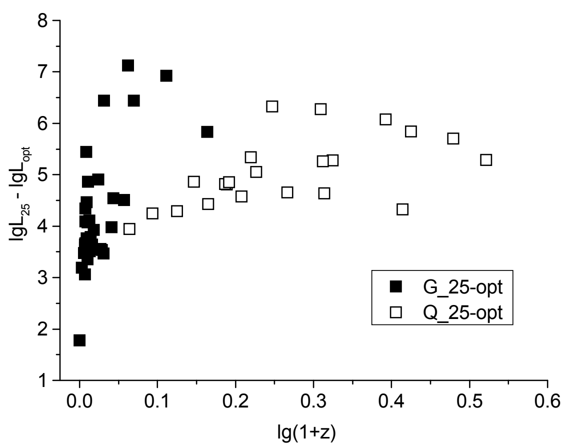

Figure 2. The ratio of luminosity at 25 MHz and optical luminosity against the redshift for jet objects

We have also seen the relation between the radio spectral index and the redshift for jet objects (Fig. 4). This plot indicates an quasiperiodic cosmological variation of spectral indices of jet sources.

CONCLUSIONS

The relation between the luminosity of galaxies and quasars and the redshift corresponds to the synchrotron mechanism of radiation and indicates the cosmological evolution of luminosity.

The evidence of correlation between the jet velocities and redshifts is derived from our jet objects sample.

The value of jet propagation velocity derived from the estimation of the minimal source age points to the sublight velocity values.

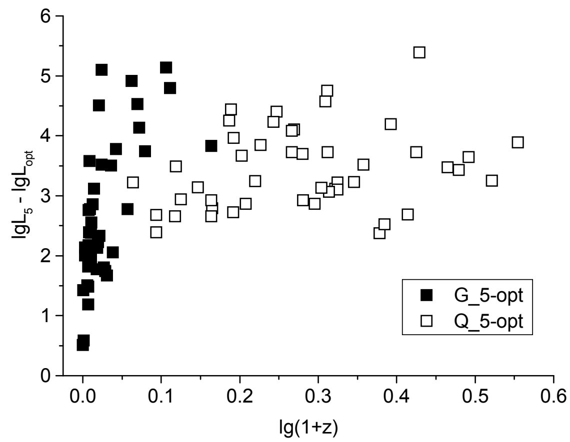

Figure 3. The ratio of luminosity both at 5 GHz and optical against the redshift for jet objects

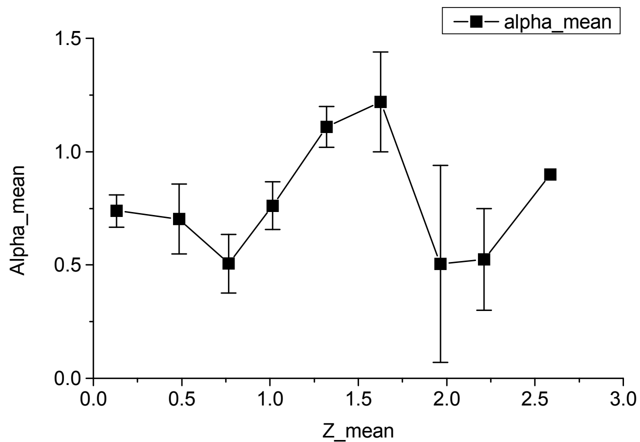

Figure 4. The spectral index against the redshift for jet objects

The magnetic field strength of jet objects ranges from 10^{-2} to 10^{-5} G.
The relation between the radio spectral index and the redshift for jet sources has a quasiperiodical character.
The characteristic age of jet objects is $10^6 \div 10^8$ years.

[1] *Braude S. Ya., Miroshnichenko A. P., Sokolov K. P., et al.* Decametric survey of discrete sources in the Northern Sky. VII // Astrophys. and Space Sci.–1981.–**74**, N 2.–P. 409–451.

[2] *Braude S. Ya., Miroshnichenko A. P., Rashkovski S. L., et al.* Decametric survey of discrete sources in the Northern Sky. XIII // Kinematics and Physics of Celestial Bodies.–2003.–**19**, N 4.–P. 291–306.

[3] *Bridle A., Perley K.* Extragalactic Radio Jets // Annu. Rev. Astron. and Astrophys.–1984.–**22**.–P. 319–358.

[4] *Ginzburg V. L.* Theoretical Physics and Astrophysics.–Moscow: Nauka, 1987.–487 p. (in Russian).

[5] *Kuhr H., Nauber U., Pauling-Toth I., et al.* A catalogue of radio sources.–Bonn: Max-Plank-Institute fur Radioastronomie, 1981.–337 p.

[6] *Lara L., Cotton W., Feretti L., et al.* A new sample of large angular size radio galaxies. I // NRAO Preprint.–2001, N 3.–46 p.

[7] *Lawrence C., Bennett C., Hewitt J., et al.* 5 GHz radio structure and optical identifications of sources from the MG survey. II // Astrophys. J.–1986.–**61**, N 1.–P. 105–157.

[8] *Veron-Cetti M.-P., Veron P.* A catalogue of quasars and active nuclei // ESO Scientific Report.–1991.–N 10.–199 p.