Jet propagation velocity and environment density of giant radio sources with steep radio spectrum

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ABSTRACT

To estimate the jet propagation velocity and environment density of giant radio sources we consider the sample of galaxies and quasars with steep radio spectrum compiled from two regions of UTR-2 catalogue. The value of velocity of jet propagation is obtained from our estimates of linear size of radio structure and characteristic age of source. We have derived that values of jet propagation velocities of examined sources are ~ $10^9$ cm s$^{-1}$. The positive correlation of jet velocity and redshift of source is displayed in our sample. We use the obtained values of jet propagation for the estimates of density of jet environment, that is, density of environment at galaxies and quasars outskirts. On the assumption of equality of jet luminosity and corresponding kinetic luminosity we estimate the density of jet environment (radio structure environment) for galaxies ($10^{-26}$ g cm$^{-3}$ – $10^{-27}$ g cm$^{-3}$) and quasars ($10^{-28}$ g cm$^{-3}$). We analyse relation of environment density versus cosmological epoch for considered giant radio sources.

Keywords: steep radio spectrum, galaxy, quasar, jet propagation velocity, environment density

1 INTRODUCTION

Radio emission of cosmic sources at the decameter band is non-thermal, that is, their radio spectra have power form. The great interest is excited by the radio sources with steep low-frequency spectrum (the spectral index value is greater than 1). Due to spectrum steepness the values of flux densities of these sources are small at high frequencies, making difficult to study their properties largely. So, the observations of decametre emission of radio sources have advantage at the determination of many astrophysical characteristics of objects and their evolution (Konovalenko et al. 2016). As we have obtained (Miroshnichenko, 2010, 2012, 2013, 2015) the properties of steep-spectrum sources from the UTR-2 catalogue (Braude et al., 1981a, 1981b, 2003) are peculiar: all galaxies and quasars with steep radio spectrum have high luminosity (the monochromatic radio luminosity at 25 MHz is ~ $10^{28}$ W/(Hz ster)), giant linear size of radio image (~ Mpc), great characteristic age (~ $10^8$ years). Giant size of radio structure of these sources is connected with great extent of jets emanated from active nuclei of objects. Such extent may indicate on the great velocity of jet propagation. Besides, the low density of extragalactic medium may provide the jet propagation on the Mpc – scales.
2 JET PROPAGATION VELOCITIES OF STEEP-SPECTRUM SOURCES

In order to estimate the jet propagation velocity and the density of their environment we consider the sample of galaxies and quasars with low-frequency steep radio spectrum compiled from two regions of UTR-2 catalogue (declinations are from −13 degrees to +20 degrees and from +30 degrees to 40 degrees (Miroshnichenko, 2012, 2013, 2014)). At the selection criteria (the spectral index value at the decametre band is greater than 1 and the flux density of radio emission at 25 MHz is $S_{25} > 10$ Jy) we have identified 130 galaxies and 91 quasars with giant radio structures. The NED database has been used for optical identifications and angular sizes of examined objects. All calculations of physical characteristics of objects have been held at the cosmological parameters $\Omega_m = 0.27$, $\Omega_\Lambda = 0.73$, $H_0 = 71$ km/(s Mpc) (Miroshnichenko, 2010, 2012, 2013, 2014). Our sample displays the sources with two types of steep low-frequency radio spectra: type S (linear steep spectrum) and type C+ (break steep spectrum), including 78 galaxies with type S ($G_S$), 52 galaxies with type C+ ($G_{C+}$), 55 quasars with type S ($Q_S$), and 36 quasars with type C+ ($Q_{C+}$).

The value of velocity of jet propagation $V_j$ is obtained from our estimates of linear size of radio structure $R$ and characteristic age of source $t$ (Miroshnichenko, 2005):

$$V_j = \frac{R}{2 t}$$

(1)

It turns out that the values of jet propagation velocities of sample’s sources are $\sim 10^9$ cm/s. So, these are subrelativistic both for galaxies and quasars with steep radio spectra at given four subsamples: $G_S$, $G_{C+}$, $Q_S$, $Q_{C+}$. This conclusion follows from the obtained mean values of jet propagation velocity $<V_j>$ for examined classes of sample’s objects:

$G_S$ $<V_j> = 2.97*10^9$ (+- 0.67*10^9) cm/s ;

$G_{C+}$ $<V_j> = 5.78*10^8$ (+- 4.09*10^8) cm/s ;

$Q_S$ $<V_j> = 3.12*10^9$ (+- 0.31*10^9) cm/s ;

$Q_{C+}$ $<V_j> = 1.65*10^9$ (+- 0.45*10^9) cm/s

Note, that 10 per cent of examined sample’s galaxies with steep radio spectrum are members of galaxy clusters. We have obtained for these galaxies the mean velocity value $<V_j>_{\text{cluster}} = 5.64*10^8$ (+- 1.43*10^8) cm/s, including for galaxies with spectral type S one is $<V_j>_{\text{cluster}} = 7.19*10^8$ (+- 1.55*10^8) cm/s, and for galaxies with spectral type C+ one is $<V_j>_{\text{cluster}} = 4.94*10^7$ (+- 0.51*10^7) cm/s. Thus, the values of jet propagation velocity of sample’s cluster galaxies are smaller than these for other sample’s galaxies. Taking into account that cluster environment is denser than extragalactic environment we can see the slowing of the jet propagation in galaxy clusters.
Galaxies and quasars of our sample cover the wide range of redshifts $z$ (from $z = 0.006$ to $z = 3.57$), allowing the study their derived parameters versus the redshifts. All four classes of examined sources display the positive correlation of jet propagation velocity and redshift (see Fig. 1-4):

- $G_S$: $V_j \sim (1+z)^{2.71} (\pm 0.09)$,
- $Gc+$: $V_j \sim (1+z)^{5.23} (\pm 0.21)$,
- $Q_S$: $V_j \sim (1+z)^{2.31} (\pm 0.13)$,
- $Qc+$: $V_j \sim (1+z)^{4.69} (\pm 0.29)$.

As one can see from determined relations (Fig. 1-4), the jet propagation velocity for sources with steep radio spectrum is greater for more early cosmological epochs and it decreases to small redshifts by power law. At that the more prominent evolution of the jet velocity is observed for examined objects with spectral type C+ ($G_{C+}$ and $Q_{C+}$). This may be due to an activity recurrence of nuclei of sources with steep spectrum C+.

### 3 ESTIMATES OF JET ENVIRONMENT DENSITIES OF STEEP-SPECTRUM SOURCES

We use the obtained values of the jet propagation velocities $V_j$ for the estimates of the jet environment densities, that is, density of environment at galaxies’s and quasars’s outskirts in given sample. Note the linear sizes of examined objects have values of about Mpc (Miroshnichenko, 2012). To calculate the densities we assume the equality of jet luminosity $L_j$ and corresponding kinetic luminosity $L_k$:

$$L_j = \frac{4}{3} \pi j^2 V_j U$$  \hspace{1cm} (2)

$$L_k = \frac{\pi}{2} r_j^2 \rho_j V_j^3$$  \hspace{1cm} (3)

where $r_j$ is the jet radius, $U = \frac{7 B^2}{3 8\pi}$ is the minimal energy density of a source, $B$ is the magnetic field strength of a source, $\rho_j$ is the jet density.

It follows from (2) and (3) that the jet density (environment density) $\rho_j$ has value [5]:

$$\rho_j = \frac{7B^2}{9\pi V_j^2}$$  \hspace{1cm} (4)

From (4) we get the estimates of density of jet environment $\rho_j$ for galaxies and quasars with steep radio spectra. For examined galaxies these values are from $10^{-26}$ g/cm$^3$ to $10^{-27}$ g/cm$^3$, and
for examined quasars these are of about $\sim 10^{-28}$ g/cm$^3$. The mean values of jet environment density $\langle \rho_j \rangle$ for each class of sample objects are next:

- $G_S \quad \langle \rho_j \rangle = 1.32 \times 10^{-27} \pm 0.36 \times 10^{-27}$ g/cm$^3$,
- $Gc+ \quad \langle \rho_j \rangle = 1.30 \times 10^{-26} \pm 0.32 \times 10^{-26}$ g/cm$^3$,
- $Q_S \quad \langle \rho_j \rangle = 6.29 \times 10^{-29} \pm 1.32 \times 10^{-29}$ g/cm$^3$,
- $Qc+ \quad \langle \rho_j \rangle = 1.08 \times 10^{-28} \pm 0.43 \times 10^{-28}$ g/cm$^3$.

Also, we obtain the environment density $\rho_{j\text{, cluster}}$ for the sample’s galaxies belonging to galaxy clusters (their number is near 10 per cent of all sample’s galaxies). It turns out that this value is greater than one for isolated sample’s galaxies. The mean value of environment density for cluster galaxies is $\langle \rho_j \rangle_{\text{cluster}} = 6.80 \times 10^{-27} \pm 2.83 \times 10^{-27}$ g/cm$^3$. In particular, this value is $\langle \rho_j \rangle_{\text{cluster}} = 3.19 \times 10^{-27} \pm 1.42 \times 10^{-27}$ g/cm$^3$ for galaxies with spectral type S, and one is $\langle \rho_j \rangle_{\text{cluster}} = 1.89 \times 10^{-26} \pm 0.91 \times 10^{-26}$ g/cm$^3$ for galaxies with spectral type C+.

Thus, the jet environment of galaxies with steep low-frequency radio spectrum (especially for type C+) is denser than the jet environment of quasars. It is interesting to consider the relation of jet environment density and redshift of examined sources (see Fig. 5-8):

- $G_S \quad \rho_j \sim (1 + z)^{6.28 \pm 0.25}$ ;
- $Gc+ \quad \rho_j \sim (1 + z)^{-11.49 \pm 0.87}$ ;
- $Q_S \quad \rho_j \sim (1 + z)^{-5.10 \pm 0.32}$ ;
- $Qc+ \quad \rho_j \sim (1 + z)^{-9.54 \pm 1.04}$ .

As one can see, the sample’s galaxies and quasars with steep radio spectrum of type C+ reveal the essential evolution of jet environment density (Fig. 5-8).

### 4 CONCLUSIONS

At continuation of the examination of sources with low-frequency steep spectrum from the UTR-2 catalogue we have derived some important physical features of giant radio sources:

*Jet propagation velocities of giant steep-spectrum radio sources are subrelativistic (\sim 0.1 light velocity).

* Galaxies and quasars with break steep spectrum (type C+) have more strong evolution of jet propagation velocity than these with linear steep spectrum (type S). This may indicate on the nucleus activity recurrence for objects with steep radio spectrum C+. 


Galaxies and quasars with steep radio spectra of types С+ and S display strong evolution of their jet environment density. At that the value of jet environment density is greater for galaxies, especially, for galaxies of spectral type С+.

Figure 1. Jet propagation velocities of galaxies with linear steep spectra versus redshift.

Figure 2. Jet propagation velocities of galaxies with break steep spectra versus redshift.
Figure 3. Jet propagation velocities of quasars with linear steep spectra versus redshift.

Figure 4. Jet propagation velocities of quasars with break steep spectra versus redshift.
Figure 5. Jet environment densities of galaxies with linear steep spectra versus redshift.

Figure 6. Jet environment densities of galaxies with break steep spectra versus redshift.
Figure 7. Jet environment densities of quasars with linear steep spectra versus redshift.

Figure 8. Jet environment densities of quasars with break steep spectra versus redshift.
