# EVOLUTION OF LUMINOSITY-LINEAR SIZE RELATION FOR SOURCES WITH STEEP RADIO SPECTRUM

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**Abstract.** In this work we continue to study some evolution properties of the peculiar population of sources with low-frequency steep radio spectrum. Base upon the catalogue of the extragalactic sources obtained at the decametre band with the Ukrainian UTR-2 radio telescope (Braude et al.) we have formed samples of sources with steep radio spectra of two types – with linear steep spectrum (S) and low-frequency steepness after a break (C+). Note, that the values of spectral indices of examined sources are greater than 1. At the frame of LambdaCDM-model of the Universe the sample's galaxies and quasars with steep spectrum of both types (S and C+) posses the very extended radio structure (~Mpc) and the great luminosity (~$10^{28}$ *W/Hz ster* at the frequency 25 MHz). To obtain the relation of low-frequency luminosity, at the frequency 25 MHz, and linear size of sample objects we determine one at the different redshift ranges. The derived relations show positive power trend for the considered galaxies and quasars. Also, we obtain the cosmological evolution of source's linear size when study one at the narrow luminosity bins. Since the object's luminosity ratio for monochromatic luminosities is independent from the Universe model, we examine the luminosity ratio – linear size relation at different frequency ranges. It is very interesting that obtained luminosity ratio – linear size relations at higher frequency ranges (infrared, X-ray) display two branches of evolution of steep-spectrum radio sources, testifying on source's activity recurrence.

## Introduction.

Radio sources with low-frequency steep spectrum of both spectral types (S and C+) correspond to conception of the long evolution of this class of sources, when the critical frequency of the synchrotron emission can displace to values less than 10 MHz. The detailed study of the identified radio sources with steep spectra at the decametre band (Miroshnichenko, 2010, 2012a, 2012b, 2013, 2014, 2015) shows, that these radio sources have interesting properties. In particular, these objects have great luminosity ($L_{25} \sim 10^{28}$ W/Hz ster), great characteristic age ($10^8$ years), giant radio structure (~ 1 Mpc). It is noteworthy that the obtained energy ratio for steep-spectrum sources (Miroshnichenko, 2014) testifies that the energy of relativistic particles prevails over the energy of magnetic field in the galaxies and quasars with steep radio spectra.

For the purpose of further study of the peculiar class of objects – galaxies and quasars with low-frequency steep radio spectrum (the spectral index values are larger than 1), we consider the relation of their radio luminosity and linear size. This relation, as pointed out Shklovskii (1963), may contain the information on the source's evolution. A number of authors (Kapahi, 1989; Gopal-Krishna & Kulkarni, 1992; Neeser et al 1995; Singal, 1996; Luo & Sadler, 2010) have studied the dependence of linear size on luminosity for radio galaxies and quasars, but there is no the single opinion. For instance, Kapahi (1989) obtained for powerful radio galaxies an increase of source's sizes at large luminosities, while Luo & Sadler (2010) established the same trend only for sources with low radio luminosity. Note, that majority of the authors have used samples of objects irrespective of range of the spectral indices.

## Luminosity – linear size relation for sources with steep radio spectrum

The examined sample of objects with steep spectrum is compiled with the UTR-2 (Grakovo) catalogue of extragalactic sources detected with the UTR-2 telescope at the decameter band (Braude et al.). Within the declination ranges from -13 to +20 degrees and from 30 to 40 degrees of the UTR-2 catalogue we have identified 78 galaxies and 55 quasars with linear steep spectrum (S-type) and 52 galaxies and 36 quasars with break steep spectrum (C+type) (with flux density at 25 MHz $S_{25} > 10$ Jy and spectral index larger 1). We use the NED database (http://nedwww.ipac.caltech.edu) for the high-frequency and optical identifications. At that the redshift range of objects is enough vast and forms 0.006 – 3.570.

Estimates of the angular sizes of examined sources we have derived from the corresponding radio images of the NVVS survey (at 1400 MHz), presented at NED database. We suppose that angular sizes from NVSS are close to angular sizes of corresponding sources at low frequencies. Calculations of the physical parameters of considered radio sources are carried out at cosmological parameters $\Omega_m = 0.27$, $\Omega_\lambda = 0.73$, $H_0 = 71$ km/s Mpc .

We examine relationship $L_{25}$ (R) of radio luminosity at 25 MHz and linear size for each class of objects in our sample, that is, in 4 subsamples, which are: galaxies with linear steep spectrum ($G_S$), galaxies with break steep spectrum ($G_{C+}$), quasars with linear steep spectrum ($Q_S$), quasars with break steep spectrum ($Q_{C+}$). At this, the relation $L_{25}$ (R) is considered at different ranges of redshift z relatively to median values $z_{median}$ in given subsamples (see Table 1).

The object's luminosity ratios at different frequency ranges are independent from the Universe model, and we consider their correlation with linear size. The trend to increase of contribution of the decametre emission for more extended sources is noticeable in the relation of ratio of monochromatic luminosities and linear size of sources (Figure 1, Figure 2). As one can see, the obtained luminosity ratio – linear size relations for examined galaxies and quasars at higher frequency ranges (infrared, X-ray) display two branches of evolution of steep-spectrum radio sources (Figure 3). These may testify on the recurrence of nucleus activity in objects with steep radio spectrum.

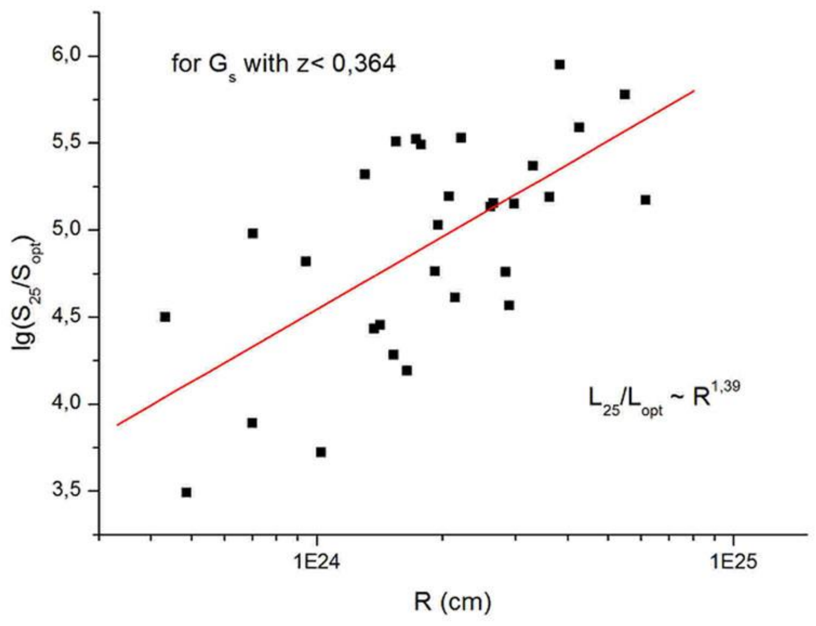


Figure 1. Ratio of luminosities at decametre and optical bands versus linear size for $G_S$ at $z < z_{median}$

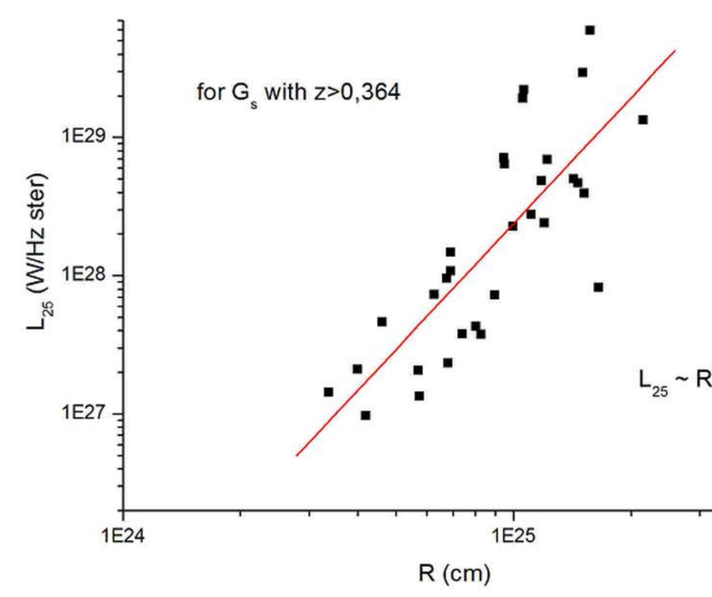


Figure 2. Luminosities at decametre band versus linear size for $G_S$ at $z > z_{median}$

Table 1.Relations $L_{25}$ (R) in 4 subsamples ($G_S$, $G_{C+}$, $Q_S$, $Q_{C+}$) at redshift ranges z, less than $z_{median}$ , and larger than $z_{median}$

| Objects /and their $z_{median}$ | $L_{25}$ (R) at $z < z_{median}$ | $L_{25}$ (R) at $z > z_{median}$ |
|---|---|---|
| $G_S$ /0.364 | $L_{25} \sim R^{1.53\ (+-0.27)}$ | $L_{25} \sim R^{3.03(+-0.43)}$ |
| $G_{C+}$ /0.182 | $L_{25} \sim R^{0.98\ (+-0.40)}$ | $L_{25} \sim R^{2.67(+-0.70)}$ |
| $Q_S$ /0.944 | $L_{25} \sim R^{2.20\ (+-0.60)}$ | $L_{25} \sim R^{1.21(+-0.75)}$ |
| $Q_{C+}$ /0.857 | $L_{25} \sim R^{0.51\ (+-0.44)}$ | $L_{25} \sim R^{1.57(+-0.98)}$ |

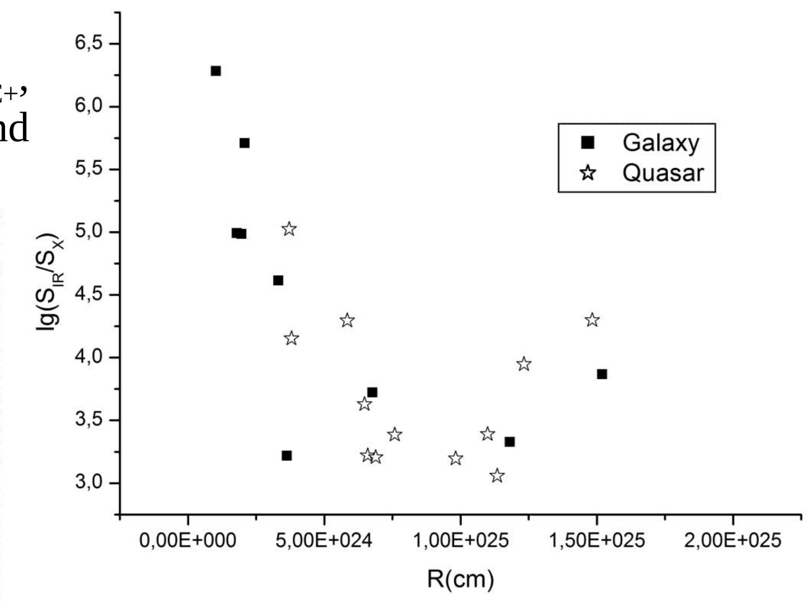


Figure 3. The ratio of monochromatic luminosities of examined sources at the infrared and X-rayl bands versus the linear size (for type S)

Also, we study the relation $L_{25}$ (R) at the same range of redshifts : z = 0 – 0.5 for each subsample of objects. One can see that obtained relations have power shape : for $G_S$ : $L_{25} \sim R^{1.93\ (+-0.22)}$ , for $G_{C+}$ : $L_{25} \sim R^{1.81\ (+-0.25)}$ , for $Q_S$ : $L_{25} \sim R^{1.80\ (+-1.06)}$ for $Q_{C+}$ : $L_{25} \sim R^{0.25\ (+-0.94)}$. So, galaxies and quasars with steep spectrum and giant radio structure reveal the positive correlation of their radio luminosity and linear size.

The noticeable disperse at the each found relation $L_{25}$ (R) for sources with steep radio spectrum may be caused by cosmological evolution of linear size, that is, the relation of linear size and redshift, R (z).

To exclude the influence of itself cosmological model used at calculation of source's physical parameters, we search the relation R (z) only at given bins of luminosity $L_{25}$ (at bin value $\Delta \lg L_{25} = 1$). For example, at the luminosity bin $L_{25} = 10^{28} - 10^{29}$ (W/Hz ster) the derived relation R (z) shows power trend in 4 subsamples, indicating the cosmological evolution of linear size of objects:
for $G_S$ : $R \sim (1+z)^{0.74\ (+-0.38)}$ , for $G_{C+}$ : $R \sim (1+z)^{0.97\ (+-0.27)}$ ,
for $Q_S$ : $R \sim (1+z)^{0.83\ (+-0.52)}$ , for $Q_{C+}$ : $R \sim (1+z)^{1.87\ (+-0.42)}$ .

## Conclusions

Radio sources with low-frequency steep spectrum and giant structure display the positive correlation of their luminosity and linear size.

The cosmological evolution of linear size of galaxies and quasars with steep radio spectrum is revealed.

The found relation of decametre luminosity and linear size means the huge power of the "central engine" of sources with steep radio spectrum, which provides the rejection of jets to giant distances.

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