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THE JET KINETIC LUMINOSITIES FOR THE UTR-2 SOURCES WITH THE STEEP LOW-FREQUENCY SPECTRA

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ABSTRACT. Earlier we have determined that the UTR-2 radio sources with steep linear spectra possess greater jet propagation velocity and lesser characteristic age than the UTR-2 radio sources with steep break spectra. Also examined galaxies and quasars with steep break spectra display greater mean values of the central black hole masses and mass accretion rates, than corresponding these for galaxies and quasars with steep linear spectra. Besides, as we have determined, the radio structure of the UTR-2 steep-spectrum sources is giant, its linear size has Mpc-scale. The source's giant structure is formed by jets with enveloped radio lobes. So, this indicates on the powerful jets of the radio sources with the steep low-frequency spectra. Since the source jets are connected with the accretion disk of the source, it is important to examine relations of their physical characteristics. With this purpose we obtain estimates of the jet kinetic luminosity for the UTR-2 steep-spectrum sources on the assumption of the equality of the corresponding mass accretion rate and the jet matter flux. Using our calculated values of the jet propagation velocity and the mass accretion rate for the UTR-2 steep-spectrum galaxies and quasars, we estimate their jet kinetic luminosities. The obtained values of the jet kinetic luminosities are ~ 10^{45} erg/s, pointing out the great power of jets for the examined steep-spectrum sources. It is essential, that the examined objects display the relation of their kinetic luminosity and corresponding redshift (cosmological evolution).

Keywords: Steep-spectrum radio sources, jets, galaxies, quasars, mass accretion rate, kinetic luminosity.

АНОТАЦІЯ. Раніше ми отримали, що радіоджерела з каталогу УТР-2, які мають круті лінійні спектри, мають більшу швидкість поширення джетів і менший характерний вік, ніж УТР-2 джерела з крутими спектрами зі зламом. Також досліджувані галактики і квазари з крутими спектрами зі зламом проявляють більші середні величини мас центральних чорних дір і темпів акреції маси, ніж відповідні величини для галактик і квазарів з крутими лінійними спектрами. Крім того, ми отримали, що радіоструктура УТР-2 джерел з крутими спектрами є велетенською, її лінійний розмір має мегапарсековий масштаб. Ця велетенська структура джерел формується джетами та їхніми радіопелюстками. Отже, це вказує на потужні джети радіоджерел з крутими низькочастотними спектрами. Оскільки джети джерела пов'язані з акреційним диском джерела, важливо дослідити співвідношення їх фізичних характеристик. З цією метою ми отримуємо оцінки кінетичної світності джетів для УТР-2 джерел з крутими спектрами, припускаючи рівність відповідного темпу акреції маси та потоку речовини джета. Використовуючи обчислені нами величини швидкості поширення джетів і темпу акреції маси для УТР-2 галактик і квазарів з крутим спектром, ми одержали оцінку кінетичної світності їхніх джетів. Отримані значення кінетичної світності джетів становлять ~ 10^{45} ерг/с , вказуючи на велику потужність джетів розглянутих джерел з крутими спектрами. Важливо, що досліджувані об'єкти показують залежність їхньої кінетичної світності відносно відповідного червоного зміщення (космологічну еволюцію).

Ключові слова: Радіоджерела з крутим спектром, джети, галактики, квазари, темп акреції маси, кінетична світність.

1. Introduction

It is known that extragalactic radio sources – galaxies and quasars contain active nuclei. In active nuclei of galaxies and quasars the supermassive black hole accretes the surrounding matter. Modern studies show the structure of the active galactic nuclei at the scales by order of some tenth of light year (Fig. 1). This structure includes the supermassive black hole, accretion disk with its crown, gas-dust torus and extended jets – narrow beams of energetic particles. The emission of accretion disk is connected with optical and high-frequency radio emission. The crown of accretion disk is emitter of X-rays. The gas-dust torus is connected with infrared emission, and jets and their radio lobes are bright regions of low-frequency radio emission. At the decameter wavelengths – at the lowest frequency range for the ground radio telescopes – the jets may be very intensive at the steep spectrum of synchrotron radiation of the source. Indeed, the UTR-2 steep spectrum sources (with value of the spectral indices $\alpha \geq 1$) possess the great luminosity at the decameter wavelengths.

2. Estimate of the jet kinetic luminosities for the UTR-2 sources with the steep low-frequency spectra

As we have derived before (Miroshnichenko, 2010 – 2021), sources with the steep low-frequency spectra from

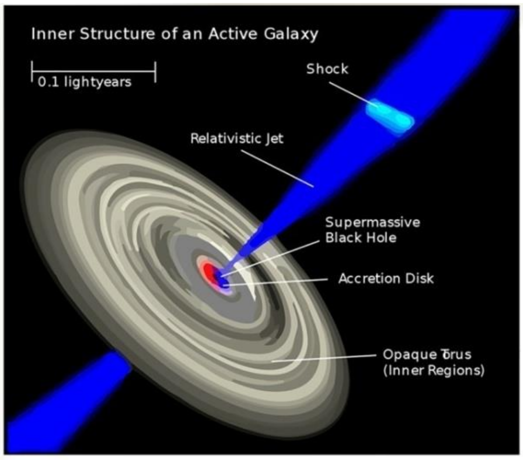


Figure 1: The scheme of active nucleus of radio source

the UTR-2 catalogue (Braude et al., 1978, 1979, 1981, 2003) have great monochromatic luminosity at the decameter band (the monochromatic luminosity at the frequency 25 MHz is ~ 10^{28} W/(Hz·sterad), the giant radio structure (its linear size is ~ Mpc), the great characteristic age (10^8 years), the sublight jet propagation velocity (~ 0.1 s), the great mass of the central black hole (10^8 – 10^9 Mo). These sources have two spectral types: S (steep linear radio spectrum) and C+ (steep break radio spectrum) (Fig. 2). For determining of the characteristics of the steep-spectrum sources, we examine the sample of these sources from the UTR-2 catalogue (78 galaxies and 55 quasars with steep linear radio spectrum, and 54 galaxies and 36 quasars with steep break radio spectrum). Corresponding identifications of the sample sources in the centimeter, infrared, optical, X-ray bands have been made with the NED data base. As the result we have composed 4 subsamples: 53 galaxies with steep linear spectrum (Gs), 37 galaxies with steep break spectrum (Gc+), 45 quasars with steep linear spectrum (Qs), 29 quasars with steep break spectrum (Qc+).

Before (Miroshnichenko, 2019) we have determined that the UTR-2 sources with steep linear spectrum possess greater jet propagation velocity than the UTR-2 radio sources with steep break spectrum:

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

Gc+ $< V_j > = 5.78*10^8$ (+- $4.09*10^8$) cm/s ;

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

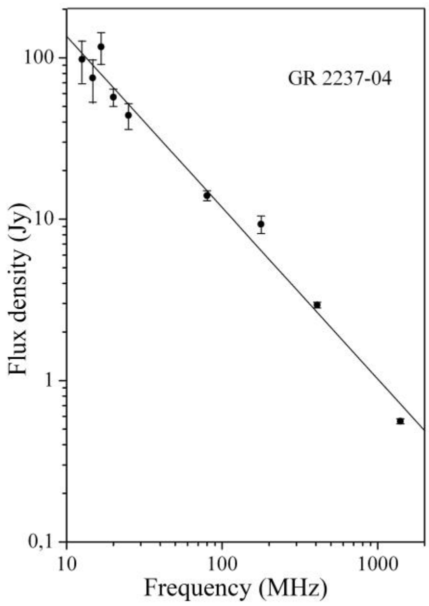
Qc+ $< V_j > = 1.65*10^9$ (+- $0.45*10^9$) cm/s .

Also, the examined galaxies and quasars with steep break spectrum display greater mean values of the central black hole masses and mass accretion rates, than corresponding ones for galaxies and quasars with steep linear spectrum (Miroshnichenko, 2018).

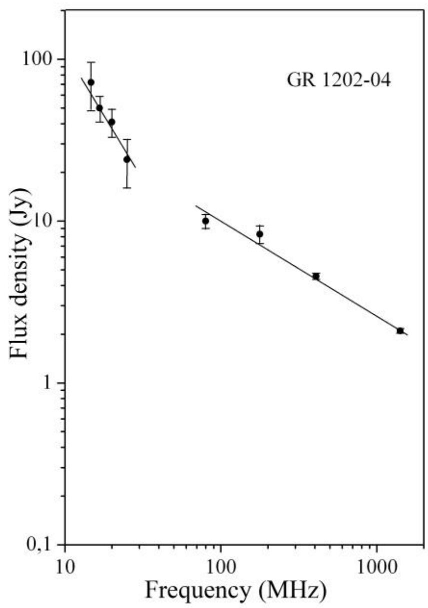
Since the source jets are connected with the accretion disk of the source, it is important to examine relations of their physical characteristics. The process of accretion on the black hole of source is characterized by the mass accretion rate $\left(\frac{dM}{dt}\right)_{Edd}$ (Shakura & Sunyaev, 1973). In the theory of accretion disks it is usually assumed that the luminosity of the disk is bounded by the Eddington luminosity (Frank et al., 2002; Li, 2012). The Eddington luminosity L_{Edd} is the limit luminosity of source when the light pressure is balanced with the gravity force (Shakura & Sunyaev, 1973).

We obtain the estimate of the kinetic luminosity of jets for examined sources from the assumption about the approximate equality of the mass accretion rate and the jet matter flux:

$$L_k = \frac{\dot{M}_j V_j^2}{2} \quad ,$$



a)



b)

Figure 2: Examples of spectral types S (a) and C+ (b) for steep-spectrum sources from the UTR-2 catalogue

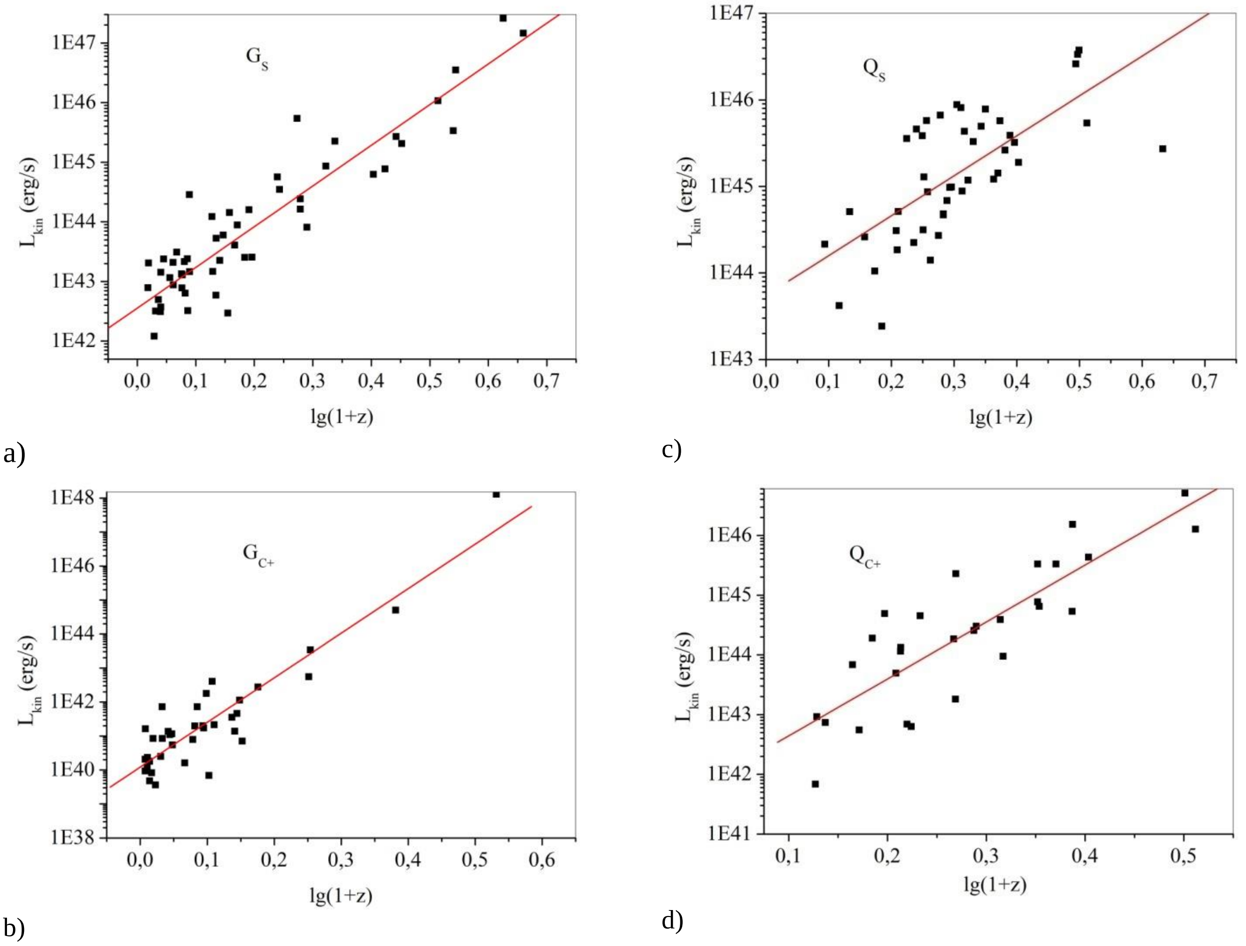


Figure 3: The relation of jet kinetic luminosity and redshift for G_S (a), G_{C+} (b), Q_S (c) and Q_{C+} (d).

where $\dot{M}$ is the jet matter flux, Vj is the jet propagation velocity. Then we obtain:

$$L_{kinet} = \frac{\dot{M}V_j^2}{2} = \frac{\left(\frac{dM}{dt}\right)_{Edd} V_j^2}{2} .$$

The derived values of the kinetic luminosity point out the powerful jets of source with low-frequency steep spectrum:

G_S $\langle L_{kinet} \rangle == 8.90(\pm 5.58)\cdot 10^{45}\ erg/s$;

G_{C+} $\langle L_{kinet} \rangle == 3.52(\pm 3.52)\cdot 10^{46}\ erg/s$;

Q_S $\langle L_{kinet} \rangle == 4.41(\pm 1.20)\cdot 10^{45}\ erg/s$;

Q_{C+} $\langle L_{kinet} \rangle == 3.35(\pm 1.83)\cdot 10^{45}\ erg/s$.

Since the examined objects cover the redshift range z = 0,017 to z = 3,57, we consider the relation of the obtained kinetic luminosities and the corresponding redshifts. The sample objects with steep break spectrum display considerable relationship from redshift in comparison with the linear spectrum objects (see Fig. 3(a,b,c,d)):

G_S $k = 0.91$

$L_{kinet} = 6.82(\pm 0.42)\lg(1+z) + 42.55(\pm 0.11)$;

G_{C+} $k = 0.91$

$L_{kinet} = 13.12(\pm 0.99)\lg(1+z) + 40.09(\pm 0.15)$;

Q_S $k = 0.70$

$L_{kinet} = 4.62(\pm 0.73)\lg(1+z) + 43.74(\pm 0.23)$;

Q_{C+} $k = 0.84$

$L_{kinet} = 9.54(\pm 1.17)\lg(1+z) + 41.69(\pm 0.35)$.

3. Conclusion

To continue the study of radio sources with steep low-frequency spectra from the UTR-2 catalogue, the estimates of the jet kinetic luminosity in these sources have been derived.

The obtained estimates of the jet kinetic luminosities point out the great power of jets of the steep-spectrum sources (10^{45} erg/s).

The relationship of the kinetic luminosity of jets and redshift (as cosmological evolution) is revealed, especially, for sources with steep break spectrum.

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