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Objects with Ultra Steep Spectra in the Central Section of the RATAN Zenith Field (RZF) Catalog

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Objects with ultra-steep spectra (USS) are the main indicator in the search for distant radio galaxies. A study of an updated sample of 73 objects with ultra-steep spectra (spectral indices $\alpha \leq -1.1$, $S_\nu \sim \nu^\alpha$) from the the central section ± 2′ of the RATAN-600 Zenith Field deep survey (RZF, 40°.5 ≤ Dec ≤ 42°.5) in the centimeter wavelength range (λ = 7.6 cm) is presented. The considered sample of USS sources turned out to be rather weak: the median flux densities $S_{3.94}$ = 6.8 mJy and $S_{1.4}$ = 34.5 mJy at 3.94 GHz and 1.4 GHz respectively. For 31 radio sources photometric redshifts (z_{ph}) were determined and optical identifications were carried out using the SDSS (DR7, DR12). Twenty-three objects turned out to be galaxies, and 8 are star-forming objects. The radio luminosity of the considered sources at a frequency of 1.4 GHz varies in the range of $1.51 \times 10^{24} \leq L_{1.4} \leq 5.17 \times 10^{27}$ W/Hz, with median $L_{1.4} \approx 4.25 \times 10^{26}$ W/Hz. Fifteen galaxies, judging by their radio luminosities $L_{1.4} > 10^{26}$ W/Hz, belong to the FR II type, 6 objects are mixed objects of the FR I − FR II types. Two galaxies with $L_{1.4} < 10^{25}$ W/Hz and $z_{ph} < 0.5$ turned out to be rare nearby galaxies of the FR I type. Nearly all these sources can be observed with the SAO 6-m telescope. The galaxies with $L_{1.4} \geq 10^{26}$ W/Hz (FR II) have r magnitudes in the range $18 \leq m_r \leq 23$. According to their activity indices, all but one of the objects are active ($R_r > 1$) with the main contribution to their integrated radio emission coming from an active nucleus.

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1. Introduction

Objects with ultra-steep spectra (USS) are of particular interest because they have become an important selection factor in the search for distant radio galaxies (HzRG). Such galaxies, as a rule, are powerful galaxies of type FR II [1]. They are often found in protocluster environments [2-4]. These objects may be associated with the first generation of super massive black holes. Powerful radio galaxies formed in the first 10% of the lifetime of the Universe have been found in very deep surveys at centimeter wavelengths with the RATAN-600 radio telescope [5-7]. The spectral index ─ redshift relation is a key tool in searches for distant radio galaxies. Detailed studies were then published [8-12]. These ones are the basis for important selection factors in distinguishing distant radio galaxies. However, the relationship between spectral curvature and redshift remains resolved incompletely. The presence of an ultra-steep spectrum is not a guarantee that the object is a high-z radio galaxy. A new method of searching for distant active galactic nuclei (AGN) with megahertz peaked-spectrum (MPS) sources was proposed [12]. A near-zenith deep survey with RATAN-600 at λ = 7.6 cm (RZF) in the region $0^h \leq$ R.A. $\leq 24^h$, 40°30′42″ ≤ Dec ≤ 42°32′42″ revealed a number of radio galaxies with ultra-steep spectra [13-15]. They may be the candidates for very distant objects. We analyze the updated data of radio sources with USS ($\alpha \leq$ -1.1, $S \sim \nu^{\alpha}$) in the central strip of the RZF survey (Dec = 41°30′42″ ± 2′).

2. Investigation of the sample of USS sources

We analyzed 73 objects with ultra-steep spectra, $\alpha \leq$ -1.1, from the sample of 448 sources in the central strip of the RZF catalog. Spectra of 18 objects were power-law shaped. Spectra of 6 sources were approximated with only two points at 1.4 GHz and 3.94 GHz. High-z radio galaxies had power-law shaped spectra and did not become steeper at high frequencies [9]. Nevertheless, they may turn over at low frequencies due to synchrotron self-absorption and free–free absorption [10]. Twenty five sources were MPS, suggesting they may be presented as the high-z radio galaxies [12]. This sample of USS sources had relatively weak flux densities (median $S_{3.94}$ = 6.8 mJy and $S_{1.4}$ = 34.5 mJy) at centimeter wavelengths. The flux-density ratio $S_{1.4}$ / $S_{3.94}$ ranged from ~1.5 to 10.5.

Optical identifications for 31 USS objects were performed using the SDSS (DR7, DR12). It turned out that 23 objects are galaxies, and 8 are star-forming objects. The radio luminosity of USS sources allows us to classify their possible nature: a radio galaxy, a radio-quiet AGN, or a star-forming galaxy. The photometric redshifts for the 31 SDSS objects with color characteristics using the PEGAS model were determined [16]. Radio luminosities were calculated using the formula from [2]

$$L_\nu = 4\pi D^2_L S_\nu (1 + z)^{-(\alpha + 1)},$$

where D_L is the photometric distance, and S_ν is the flux density at a frequency ν. The radio luminosities at 1.4 GHz lie in the range $1.51 \times 10^{24} \leq L_{1.4} \leq 17 \times 10^{27}$ W/Hz (median $L_{1.4} \sim 4.25 \times 10^{26}$ W/Hz).

The galaxies with $L_{1.4} \geq 10^{26}$ W/Hz are FR II sources. The galaxies with intermediate luminosities $10^{25} \leq L_{1.4} \leq 10^{26}$ W/Hz may be classified as FR I – FR II objects or mixed FR I / FR

II sources. Five sources with $z_{ph} > 0.5$ and $L_{1.4} > 10^{26}$ W/Hz may be classified as radio-loud AGNs [17]. Fifteen galaxies are FR II-type sources, with six of these being nearby objects ($z_{ph} < 0.5$). Four sources out of six with intermediate luminosities are nearby galaxies. Two of them with luminosities $L_{1.4} < 10^{25}$ W/Hz are of the FR I type. Such sources are very rare and reside overwhelmingly in regions of high baryonic densities. One possible explanation [9] is that nearby radio sources with ultra-steep spectra reside almost exclusively in rich clusters of galaxies.

The galaxies with $L_{1.4} \geq 10^{26}$ W/Hz (FR II type) have r magnitudes in the range $18 \leq m_r \leq 23$. The majority of these sources can be observed with the SAO 6-m telescope. The activity indices of the sources were calculated using the formula presented in [18]. Objects with $R_r > 1$ are active in the radio band, where integrated radio emission is produced by the active nucleus. Only one source in our sample has $R_r < 1$, it may be considered as a radio-quiet object or a star-forming source.

3. Conclusion

Using the updated RZF catalog at 3.94 GHz, we detected 73 sources with steep spectra at Dec = 41°30′42″ ± 2′. Cross-identification with the optical surveys (SDSS DR7, DR12) was carried out. Photometric redshifts for 31 objects were determined. It turned out that 23 sources are galaxies and 8 are star-forming objects which are mainly nearby galaxies. These radio sources are either located in a dense intergalactic media of rich clusters of galaxies or are confined within their host galaxies. Fifteen galaxies with radio luminosities $L_{1.4} \geq 10^{26}$ W/Hz are FR II-type sources, six objects with intermediate luminosities $10^{25} < L_{1.4} < 10^{26}$ W/Hz are of mixed FR I − FR II types. The remaining two galaxies with $10^{24} < L_{1.4} < 10^{25}$ W/Hz are rare USS FR I sources and reside almost exclusively in rich clusters of galaxies.

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