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CLASSIFICATION OF FLAT SPECTRUM RADIO QUASARS BY OPTICAL ACTIVITY TYPES

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We have carried out a spectral classification by the activity types for a subsample of blazars from the BZCAT v.5 Catalogue, namely the Flat Spectrum Radio Quasars (FSRQ) candidates, designated in the catalogue as BZQ subtype objects. The classification is based on the Sloan Digital Sky Survey (SDSS) homogeneous medium-resolution optical spectroscopy and along with the standard BPT-type diagnostic diagrams, we have applied our newly introduced fine classification scheme with subtypes of quasars and considering many more features. Out of 1909 BZQ objects, 618 having SDSS spectra were classified, resulting in 445 broad-line QSOs, 19 narrow-line QSOs, 138 broad-line Seyferts, 8 narrow-line Seyferts, and 2 Emission-line galaxies without a proper classification. We have calculated the absolute magnitudes and luminosities for all objects to distinguish QSOs from Seyferts, as defined by the Catalogue of QSOs and Active Galaxies, $-22^{m}.25$ separation limit. This way 148 objects changed their BZCAT subtypes between BZQ to BZG, and also 6 BZQ objects to BZU.

Keywords: *radio quasars: activity type: classification*

1. *Introduction*. Among the Active Galactic Nuclei (AGN), the most interesting are blazars with combination of two subtypes: a) BL Lac (BLL) objects and b) special types of quasars (QSO): Optically Violent Variable (OVV) and Highly Polarized Quasars (HPQ). A blazar is characterized as a very compact quasar, associated with a presumed Super Massive Black Hole (SMBH) at the center of an active giant elliptical galaxy. Blazars are the most energetic objects in the Universe [1]. The object BL Lac was originally discovered by Hoffmeister [2] as a variable star, and later it was identified by Schmitt [3] as an extragalactic source, and BL Lac type objects were assigned as one of the AGN types. They are characterized by significant optical variability, optical continuous spectrum without or with very weak absorption or emission lines, and they have radio emission. Their radio emission is typically also variable and polarized.

Massaro et al. [1] presented the blazar catalogue BZCAT v.5, where the objects are divided into 4 types: BZB (Lacertids, BL Lac or BLL), BZQ (Quasars, namely Flat Spectrum Radio Quasars, FSRQ), BZG (Galaxies), and BZU (Undetermined class). Table 1 shows the distribution of the types of blazars from the BZCAT catalogue.

Table 1

DISTRIBUTION OF THE TYPES OF BLAZARS FROM BZCAT CATALOGUE

N	Type		Number	%
1	BZB	BL Lac	1151	32.3
2	BZG	Galaxies	274	7.7
3	BZQ	Quasars	1909	53.6
4	BZU	Unclassified	227	6.4
All			3561	100.0

In our earlier papers we studied and classified BZU and BZG objects [4,5]. This paper is devoted to detailed spectral classification of type BZQ blazars from the BZCAT catalogue, the most numerous group. We aim at classifying all objects by activity types, as well as rearranging BZCAT types to have more homogeneous grouping.

2. *Studied data*. For our investigation, we have selected BZQ objects from BZCAT catalogue. We have picked out 1909 QSO candidates from Table 1, which make up our investigation data. 618 out of the 1909 BZQ objects have optical spectra in the SDSS [6]. For these objects we have carried out a detailed classification using the SDSS spectra.

Using the data from various catalogues and data bases VCV-13 [7], NASA/IPAC Extragalactic Database (NED) and SDSS [6], we have clarified the optical classification of these objects prior to our classification. We list these data in Table 2.

As it can be seen from Table 2, some objects do not have detailed optical classification, e.g., some were classified as galaxies because in optical images they have an extended shape. The table presents optical classification for all BZQ objects from SDSS, VCV-13 catalogues and NED database.

The measurements of the SDSS spectra are very often based on lines at the noise level and of low quality. As a result, automatic measurements lead to some misclassification. Thus, it is necessary to carefully check the spectra at all wavelengths and to decide which measurements should be used for further study. The lines which are used in the diagnostic diagrams are especially important ($H\beta$, [OIII] 5007 Å , [OI] 6300 Å , $H\alpha$, [NII] 6583 Å , and [SII] 6716+6731 Å) [8].

3. *Optical classification for activity types*. Mickaelian et al. [9] have introduced a new optical classification scheme (https://www.bao.am/activities/projects/21AG-1C053/mickaelian/). In this paper we have carried out optical classification using this method. To guarantee the best accuracy and consider all

Table 2

DISTRIBUTION OF TYPES OF OPTICALLY CLASSIFIED BZQ OBJECTS FROM BZCAT CATALOGUE

Classes/Subclasses	SDSS images	VCV-13	NED
S1/S1.0	-	25	10
S1.2	-	6	3
S1.5	-	6	2
S2	-	2	-
S1n	-	5	1
S?	-	1	-
BL	-	5	3
QSO	-	499	102
HP QSO	-	-	1
BAL QSO	-	-	10
HP (High Optical Polarization)	-	17	-
AGN	-	23	2
Galaxy	27	-	5
Star	591	-	-
Flat-Spectrum Radio Source (FSRS)	-	-	459
Gigahertz-Peaked Sources (GPS)	-	-	3
Total	618	589	601

possible details, we classify the objects in several ways and then consider all obtained types and subtypes:

- By the 1st diagnostic diagram (DD1) using line intensity ratios [OIII]/Hβ vs. [OI]/Hα .
- By the 2nd diagnostic diagram (DD2) using line intensity ratios [OIII]/Hβ vs. [NII]/Hα .
- By the 3rd diagnostic diagram (DD3) using line intensity ratios [OIII]/Hβ vs. [SII]/Hα .
- By comparison and using the 1st, 2nd and 3rd diagnostic diagrams simultaneously.
- By eye (considering all features and effects). Very often, the diagnostic diagrams do not give full understanding for all objects and only eye can reveal some details.

For these objects in the spectra, the lines Hα and Hβ were mainly absent (due to redshifts), so we made a classification only by the visual method.

Table 3

CLASSIFICATION OF BZQ OBJECTS USING THE SDSS SPECTRA

Classification	Number	%
QSO	348	56.31
QSO1.0	28	4.53
QSO1.2	41	6.63
QSO1.5	26	4.21
QSO1.8	1	0.16
QSO1.9	1	0.16
NLQ1.0	3	0.49
NLQ1.2	10	1.62
NLQ1.5	6	0.97
S	86	13.92
S1.0	10	1.62
S1.2	12	1.94
S1.5	20	3.24
S1.8	7	1.13
S1.9	2	0.32
S2.0	1	0.16
NLS	1	0.16
NLS1.0	1	0.16
NLS1.2	2	0.32
NLS1.5	4	0.65
Em	2	0.32
Star	1	0.16
Unknown	5	0.81
Total	618	100.00

In Table 3 and in Fig.1 we show our spectral classification for 618 BZQ objects using the SDSS spectra. It is clear from Table 3 and Fig.2 that these objects are mostly classical QSOs (about 56.31%) and other QSO subtypes (almost 17.8%).

After our new classification, 327 (52.91%) of 618 have not changed their optical class, and 291 (47.09%) of these objects have changed their optical class.

Table 4 shows our detailed classification of the 10 BZQ objects using the SDSS spectra (the full list will be available in electronic form in VizieR).

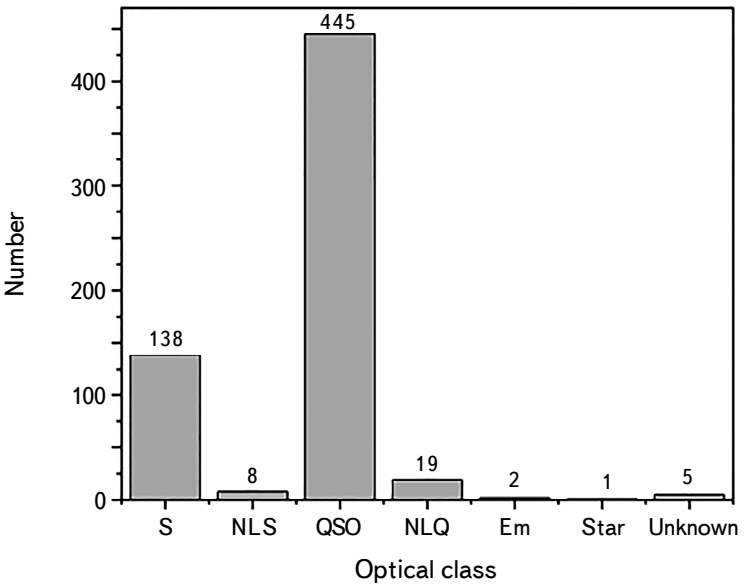

Fig.1. The new classification of the BZQ objects using the SDSS spectra.

Table 4

LIST OF THE 10 BZQ OBJECTS CLASSIFIED USING THE SDSS SPECTRA (the full list will be available in VizieR)

BZCAT name	Old class				New class		M	L
	BZCAT	SDSS	VCV-13	NED	Activity type	BZCAT class	SDSS r	$\times 10^{43}$ $L_{\odot}$
5BZQ J1254+1141	BZQ	Star	QSO	FSRS	NLQ1.0	BZQ	-24.94	309.61
5BZQ J0059+0006	BZQ	Star	S1.5	Sy 1.5	NLQ1.2	BZQ	-23.98	128.48
5BZQ J0948+0022	BZQ	Star	S1n	FSRS	NLQ1.5	BZQ	-22.78	42.36
5BZQ J1105+0202	BZQ	Galaxy	AGN	FSRS	NLS1.2	BZQ	-22.05	21.75
5BZQ J1644+2619	BZQ	Galaxy	S1n	FSRS	NLS1.5	BZQ	-21.10	9.00
5BZQ J1252+6451	BZQ	Galaxy	S1	Sy 1	S1.0	BZG	-22.23	25.57
5BZQ J2308+2008	BZQ	Star	QSO	FSRS	S1.5	BZG	-22.22	25.32
5BZQ J1631+4927	BZQ	Galaxy	AGN	FSRS	S1.8	BZG	-22.20	24.76
5BZQ J0748+2400	BZQ	Star	HP	FSRS	S2	BZG	-22.07	22.00
5BZQ J1506+3730	BZQ	Galaxy	S2	FSRS	S1.8	BZG	-20.19	3.89

4. *Absolute magnitudes and luminosities.* Having information on magnitudes from SDSS, we have calculated absolute magnitudes for BZQ objects using Eq. (1).

$$M = m + 5 - 5\log L - f(z) - \Delta m(z), \quad (1)$$

where L is the luminosity distance as defined by [10]:

$$L = \frac{c(1+z)}{H_0} \int_0^z \left[(1+z)^3 \Omega_M + \Omega_\Lambda \right]^{-0.5} dz \qquad (2)$$

z is the redshift, $f = 2.5(1-z)^{1-\alpha}$ the k correction, $\Delta m(z)$ is a correction to k considering that the spectrum of quasars is not strictly a power law of the form $S \propto \nu^{-\alpha}$ ($\alpha = -0.3$, [7]).

The following values were taken for the cosmological constants in the calculations:

$$\Omega_M = 0.29, \quad \Omega_\Lambda = 0.71, \quad H_0 = 71 \mathrm{km\,s^{-1}/Mpc}.$$

Having absolute magnitude, we counted luminosities for BZQ objects from blazars catalogue using Eq. (3).

$$L = 2.512^{M_\odot - M} L_\odot \qquad (3)$$

where $L_\odot$ and $M_\odot$ are the luminosity and the absolute magnitude of the Sun ($L_\odot = 3.83 \cdot 10^{33}$ erg/s, $M_\odot = 4.83$). Data on absolute magnitude and luminosity can be found in Table 4.

Some objects, at the beginning, using only optical spectra, were classified as Seyfert type, but after the calculation of absolute magnitudes we changed their class, if their absolute magnitude is smaller than -22.25 (the luminosity is higher). As a result, 1 NLQ changed to NLS, 1 NLQ1.0 changed to NLS1.0, 1 NLQ1.2 changed to NLS1.2, 3 NLQ1.5 changed to NLS1.5, 86 QSO changed to S (Seyfert), 9 QSO1.0 changed to S1.0, 12 QSO1.2 changed to S1.2, 19 QSO1.5 changed to S1.5, 7 QSO1.8 changed to S1.8.

5. *Results*. We selected BZQ objects from BZCAT catalogue (Table 1). 618 of the 1909 BZQ objects have optical spectra in the SDSS. For these objects we have carried out a detailed classification using the SDSS spectra. In this paper we have carried out optical classification using method given by [9]. Our optical classification results are given in Table 3 and 4.

In Table 3 and in Fig.1 we show our spectral classification for 618 BZQ objects using the SDSS spectra. It is clear from Table 3 and Fig.2 that these objects are mostly QSO (about 97%). 432 (69.9%) out of 618 have not changed optical class, only 186 (30.1%) of these objects have changed their optical class.

Some objects changed their class after estimation of absolute magnitudes (-22.25 limit between QSOs and Seyferts). As a result, 1 NLQ changed to NLS, 1 NLQ1.0 changed to NLS1.0, 1 NLQ1.2 changed to NLS1.2, 3 NLQ1.5 changed to NLS1.5, 86 QSO changed to S (Seyfert), 9 QSO1.0 changed to S1.0, 12 QSO1.2 changed to S1.2, 19 QSO1.5 changed to S1.5, 7 QSO1.8 changed to S1.8.

Having this new information on the optical classification we suggest to change

the classification of some objects in BZCAT, given by [1]: for 148 BZQ objects to BZG and for 6 BZQ objects to BZU (1 object classified as "star", 5 objects classified as "unknown").

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КЛАССИФИКАЦИЯ РАДИОКВАЗАРОВ С ПЛОСКИМ СПЕКТРОМ ПО ТИПАМ ОПТИЧЕСКОЙ АКТИВНОСТИ

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Проведена спектральная классификация кандидатов в радиоквазары с плоским спектром (FSRQ) из каталога BZCAT v.5, обозначенные в каталоге как объекты подтипа BZQ. Классификация основана на оптической спектроскопии среднего разрешения Слоановского цифрового обзора неба (SDSS), и наряду со стандартными диагностическими диаграммами BPT-типа применена недавно введенная авторами схема тонкой классификации с подтипами квазаров и учетом многих других особенностей. Из 1909 BZQ объектов классифицированы 618, которые имеют спектры SDSS, в результате чего имеем: 445 квазаров с широкими линиями, 19 квазаров с узкими линиями, 138 Сейфертов с широкими линиями, 8 Сейфертов с узкими линиями и 2 эмиссионные галактики. Рассчитаны абсолютные звездные величины и светимости для всех объектов, чтобы отличить QSO от сейфертовских галатик, как это определено каталогом квазаров и активных галактик с пределом разделения $-22^{m}.25$. В результате, 148 объектов изменили свой BZCAT подтип между BZQ и BZG, а 6 объектов с BZQ на BZU.

Ключевые слова: *радиоквазары: тип активности: классификация*

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