Astronomy Reports, Vol. 46, No. 9, 2002, pp. 697–703. Translated from Astronomicheskiĭ Zhurnal, Vol. 79, No. 9, 2002, pp. 771–777.

Classification of Optical Identifications of Radio Sources from Complete Samples

V. Chavushyan[1], R. Mujica[1], J. R. Valdes[1], A. G. Gorshkov[2], V. K. Konnikova[2], and M. G. Mingaliev[3]

[1]*Instituto Nacional de Astrofísica, Óptica y Electrónica, Luís Enrique Erro No. 1, Apdo Postal 51 y 216, Tonantzintla, Puebla, 72840 México*

[2]*Sternberg Astronomical Institute, Universitetskiĭ pr. 13, Moscow, 119899 Russia*

[3]*Special Astrophysical Observatory, Russian Academy of Sciences, Nizhniĭ Arkhyz, Karachaevo-Cherkesskaya Republic, 357169 Russia*

Received November 22, 2001; in final form, February 1, 2002

Abstract—Classifications of the optical counterparts and radio spectra of nine radio sources are presented. The observations were carried out using the 2.1-m optical telescope in Cananea (Mexico) at 4200–9000 Å and the RATAN-600 radio telescope at 0.97–21.7 GHz. Five objects have been classified as quasars (three have redshifts $z > 2$), two as BL Lac objects, one as an elliptical galaxy, and one as an absorption-line galaxy. © *2002 MAIK "Nauka/Interperiodica"*.

1. INTRODUCTION

This paper continues our work on classifying optical objects identified with radio sources from complete samples corresponding to a specified flux density. We have obtained spectra for eight objects representing optical counterparts of radio sources from a complete sample derived from the MGB survey at 4.85 GHz. The sample contains all sources with flux densities $S_{4.85} > 200$ mJy with declinations 10°–12°30′ (J2000), right ascensions 0–24$^{\rm h}$, and $|b| > 10°$. One distinctive feature of the sample is the large fraction of optical identifications obtained for the radio sources (88% of the flat-spectrum objects have identifications down to 21^m). This makes the sample promising for cosmological studies. One object is the optical counterpart of a radio source from the Zelenchuk survey ($S_{3.9} > 200$ mJy, declinations 4°–6° (B1950)), which has been studied by us since 1984 [1–3]. The results of previous work on classifications of optical objects identified with sources in this sample have been published in [4, 5].

2. RADIO AND OPTICAL OBSERVATIONS

Radio observations of the sources were carried out on the Northern quadrant of the RATAN-600 telescope at 0.97, 2.3, 3.9, 7.7, 11.1, and 21.7 GHz. The parameters of the receivers and telescope beams are given in [2, 6]. The error in the flux-density measurements dS was determined in the standard way from the scatter of the fluxes recorded every day in a given observing session. This estimate includes all types of errors: noise, calibration errors, errors in linking to the calibration signal, antenna pointing errors, etc. For long series of observations of variable sources, the rms flux error during a session is also included in the error in the average flux density. The data processing technique is described in [7].

Optical spectra of the objects were obtained in June–October, 1999 using the 2.1-meter telescope of the Guillermo Haro Observatory (Cananea, Mexico), Instituto Nacional de Astrofísica, Óptica y Electrónica (INAOE). We used the LFOSC spectrophotometer equipped with a 600 × 400 CCD matrix [8]. The detector read-out noise was 8 electrons. The spectrophotometer wavelength range was 4200–9000 Å with a dispersion of 8.2 Å/mm. The effective instrumental spectral resolution was about 16 Å.

The optical data were processed with the IRAF package, including removal of cosmic rays, flat-fielding, wavelength linearization, and flux calibration.

3. RADIO AND OPTICAL COORDINATES

Table 1 lists the positions of the objects from the catalogs of the JVAS2[1] and CLASS[2] surveys at 8.4 GHz [9, 10] and the NVSS survey at 1.4 GHz [11], differences between the radio and

[1]JVAS, Jodrell Bank–VLA Astrometric Survey.
[2]CLASS, Cosmic Lens All-Sky Survey.

Table 1. Positions and magnitudes of the objects

Object name	Radio position J2000.0		Radio−optical		R	B	Survey
	RA	DEC	ΔRA	ΔDEC			
0121+1127	$01^h21^m29\overset{s}{.}00$	$+11°27'00\overset{''}{.}53$	0.02^s	$0.73''$	17.1	17.4	JVAS
0211+1051	02 11 13.18	+10 51 34.79	−0.01	−0.01	14.8	15.1	JVAS
0323+0446	03 23 14.72	+04 46 12.59	−0.02	−0.01	18.9	19.1	JVAS
0345+1218	03 45 01.32	+12 18 48.77	−0.01	−0.13	18.5	19.5	CLASS
2203+1217	22 03 45.54	+12 17 15.63	−0.10	−2.07	17.5	18.5	NVSS
2229+1127	22 29 57.45	+11 27 37.73	0.09	−0.57	18.5	21.2	NVSS
2233+1008	22 33 58.45	+10 08 52.10	0.04	0	18.0	17.6	JVAS
2300+1037	23 00 18.32	+10 37 54.08	0	0.08	18.4	18.6	CLASS
2330+1228	23 30 09.95	+12 28 28.60	0.02	−0.40	14.5	17.5	JVAS

optical positions in right ascension and declination, and the R and B magnitudes of the objects. The optical coordinates and magnitudes were taken from the USNO catalog of astrometric standards [12] and the APM database of the Palomar Sky Survey [13]. The source names are composed from the hours and minutes of the object's right ascension and the degrees and minutes of its declination for epoch 2000.0. The rms error of the positions in the JVAS and CLASS catalogs is 0.012″ and in the NVSS survey catalog is, on average, about 0.035″ and 0.56″ for right ascension and declination, respectively.

4. RESULTS

The optical and radio spectra of all the sources are presented in Figs. 1 and 2.

4.1. 0121+1121

The May 2001 spectrum at 0.97–21.7 GHz peaks at 6.5 GHz and can be approximated by the logarithmic parabola $\log S = 1.717 + 1.208\log\nu - 0.741\log^2\nu$. (Frequencies here and below are given in Gigahertz and flux densities in milliJanskys.) Most of the flux density comes from a compact component, and the extended emission is weak. The source is absent from low-frequency surveys.

This source is identified with a blue starlike object. The optical spectrum of the object was obtained on September 13, 1999 with a 40-min exposure. We have identified the Lyα 1216 Å emission line of hydrogen, the nearby lines SiIV/OIV] 1400 Å, CIV 1549 Å and the semiforbidden line CIII] 1909 Å in the spectrum. The redshift determined from all the lines is $z = 2.485$, and the object is classified as a quasar.

4.2. 0211+1051

The radio spectrum for October 2000 has a maximum at 12 GHz. At 0.97–21.7 GHz, the spectrum can be approximated by the logarithmic parabola $\log S = 2.324 + 0.385\log\nu - 0.181\log^2\nu$. Using the 611-MHz data, we can extract a power-law component with spectral index $\alpha = -0.8 \pm 0.1$ from the spectrum. The technique used to distinguish components in complex spectra is described in [3]. After subtracting the power-law component, the resulting spectrum of the compact component can be approximated by a logarithmic parabola with its maximum at 18 GHz. The radio source was observed in 2000 and 2001; its mean flux density remained unchanged at all frequencies over the year between these observations.

We have identified the radio source with a bright, blue object ($m(B) = 15.1$). The optical spectrum was obtained on September 13, 1999 with a 45-min exposure. The spectrum shows a featureless continuum, so that the object can be classified as a BL Lac object.

4.3. 0323+0446

At 0.97–21.7-GHz, the flux density decreases toward higher frequencies, and the spectrum for December 1998 can be approximated by the logarithmic parabola $\log S = 2.377 - 0.565\log\nu + 0.199\log^2\nu$. The observations at 3.9 and 7.7 GHz show that its flux density is slowly decreasing at these frequencies: at 3.9 GHz, from 200 mJy in the Zelenchuk survey of 1980 to 130 mJy in 1998. The 1990 spectrum at 3.9–11.1-GHz was also falling toward higher frequencies, with a mean spectral index of $\alpha = -0.23$ ($S \propto \nu^\alpha$). Apparently, most of the emission at these frequencies comes from an extended component, and

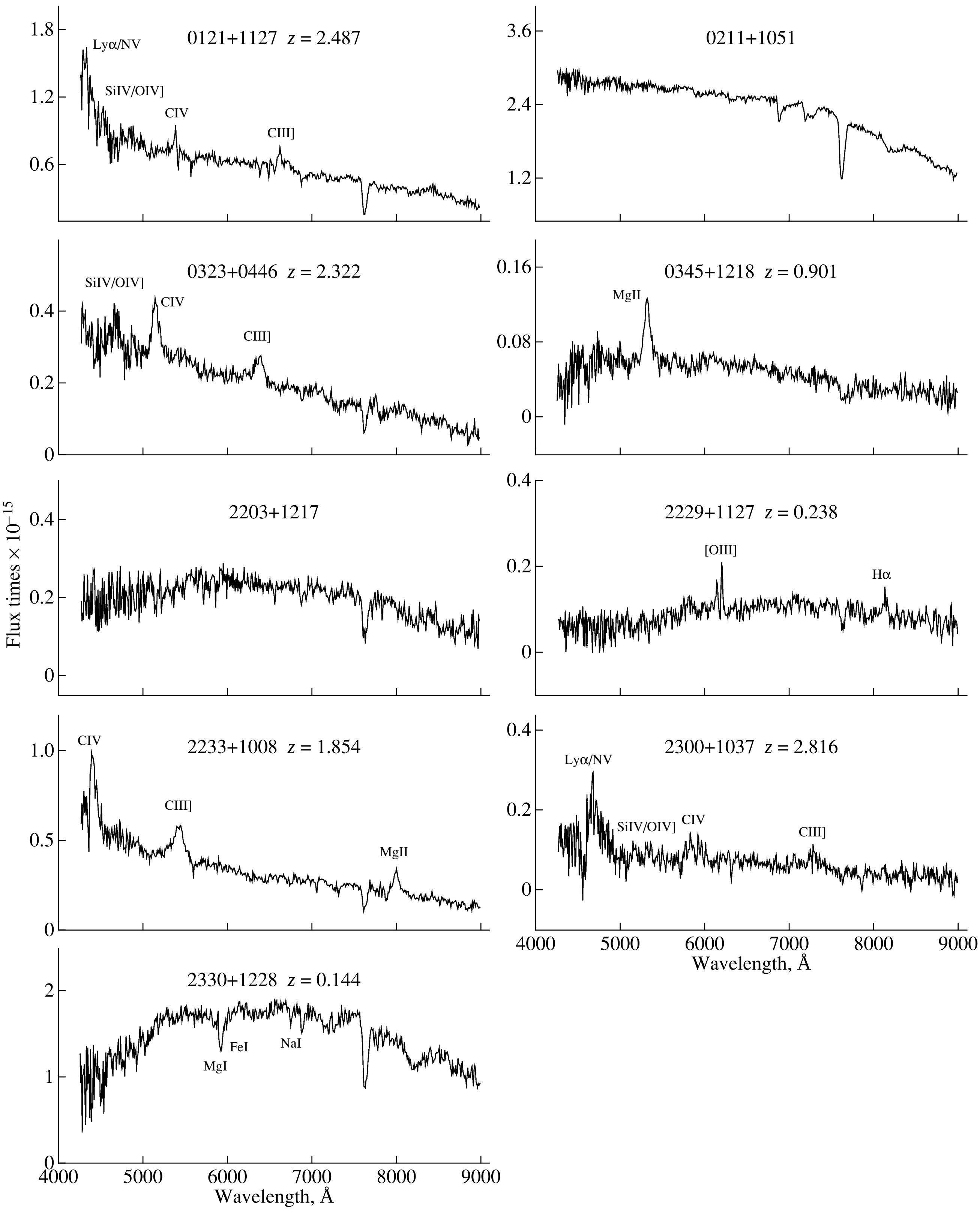

Fig. 1. Optical spectra of the objects.

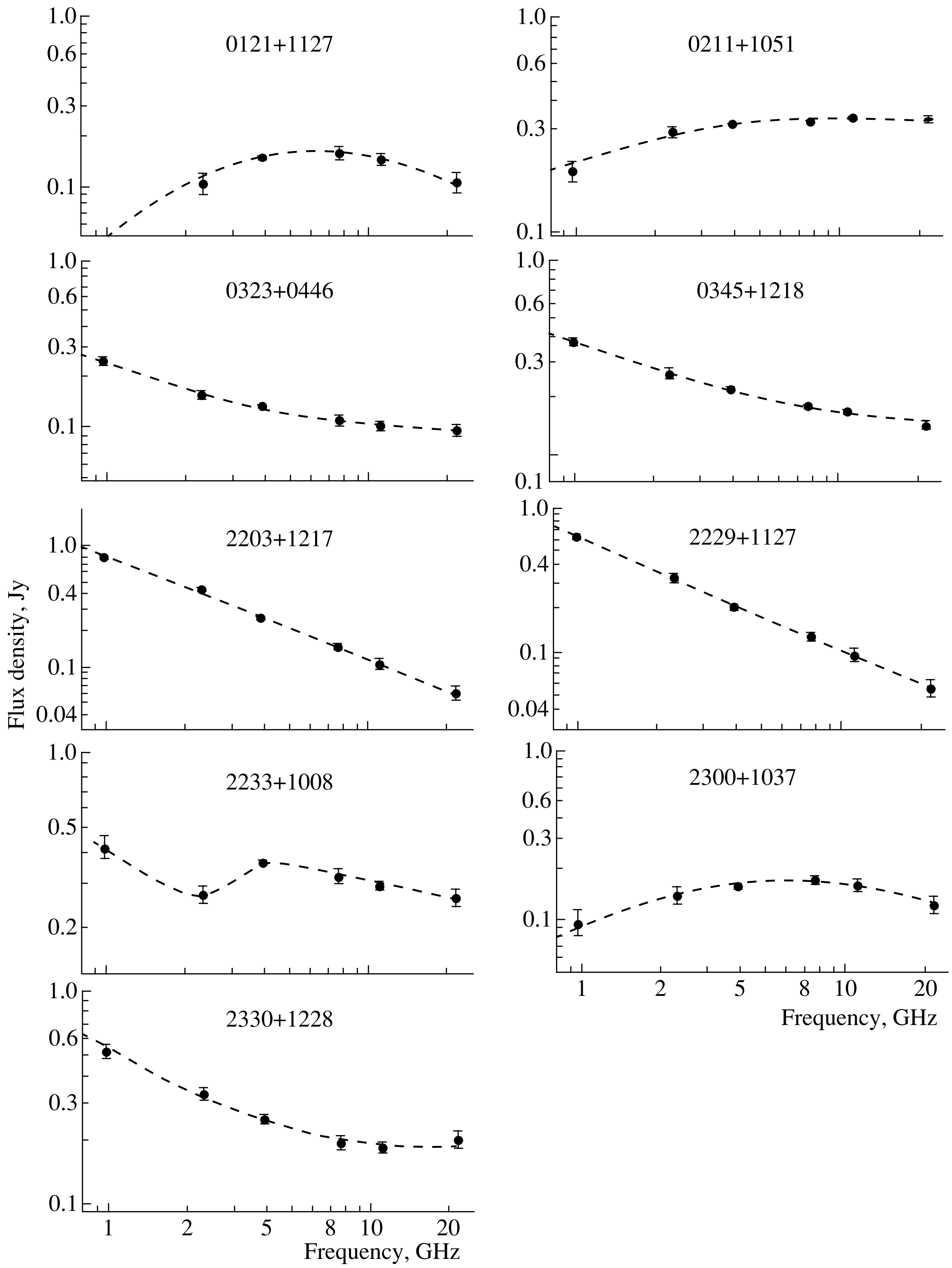

Fig. 2. Radio spectra of the objects.

the flattening of the spectrum is due to a compact component whose emission is concentrated at higher frequencies. In this case, the source spectrum can be divided into two components: a power law with spectral index $\alpha = -0.8 \pm 0.2$, whose emission dominates in the frequency range considered, and a compact component whose spectrum peaks at $\nu > 30$ GHz.

The optical spectrum was obtained on October 9, 1999 with a 60-min exposure. The strongest feature in the spectrum, which is more than 60 Å wide, has been identified with the CIV 1549 Å line of carbon. The 1394–1403 Å SiIV doublet and the OIV] 1406 Å and CIII] 1909 Å lines are also present. The redshift derived from all the lines is $z = 2.322$, and we classified the object as a quasar.

Table 2. Data concerning the optical and radio observations

Object name	Lines in the spectrum	Wavelength, lab./obs., Å	z	Object type	B	$S_{3.9\,\mathrm{GHz}}$, mJy $S_{7.7\,\mathrm{GHz}}$, mJy	α
0121+1127	Lyα	1216/4238	2.487	QSO	17.3	150 ± 5	0.08
	SiIV/OIV]	1400/4879				158 ± 15	
	CIV	1549/5398					
	CIII	1909/6653					
0211+1051	None			Lac	15.1	310 ± 5	0.08
						327 ± 7	
0323+0446	SiIV/OIV]	1400/5651	2.322	QSO	19.3	132 ± 4	−0.29
	CIV	1549/4650				108 ± 6	
	CIII	1909/6342					
0345+1218	MgII	2798/5319	0.901	QSO	19.5	215 ± 3	−0.28
						178 ± 3	
2203+1217	None			Lac	18.5	249 ± 9	−0.85
						102 ± 10	
2229+1127	[OIII]	4959/6139	0.238	ELG	19.1	208 ± 9	−0.74
	[OIII]	5007/6198				196 ± 8	
	H α	6563/8125					
2233+1008	CIV	1549/4421	1.854	QSO	17.6	360 ± 6	−0.17
	CIII	1909/5448				320 ± 20	
	MgII	2798/7985					
2300+1037	Lyα/NV	1216/4640	2.816	QSO	19.3	160 ± 5	0.12
	SiIV/OIV]	1400/5342				173 ± 10	
	CIV	1549/5911					
	CII	1909/7285					
2330+1228	MgI	5175/5920	0.144	AbsG	17.5	250 ± 10	−0.36
	FeI	5270/6029				195 ± 15	
	NaI	5896/6745					

4.4. 0345+1218

At 0.97–21.7 GHz, the source has a decreasing spectrum that flattens at high frequencies. The spectrum can be divided into a strong power-law component (comprising almost 100% of the flux density at 0.97 GHz) with spectral index $\alpha = -0.6 \pm 0.1$ and a compact component that is well approximated by a logarithmic parabola with its maximum at about 20 GHz. The total spectrum for October 2000 can be approximated by the parabola $\log S = 2.575 - 0.494 \log \nu + 0.144 \log^2 \nu$. The mean flux of the source did not change during the year between the observations in 2000 and 2001.

The optical spectrum was obtained on October 7, 1999 with a 60-min exposure. We have interpreted a strong emission feature with a width of about 80 Å as the MgII 2798 Å line at a redshift of $z = 0.901$. The object is classified as a quasar.

4.5. 2203+1218

The radio spectrum is a power-law at 0.365–21.7 GHz: $S = 779\nu^{-0.843}$.

The optical spectrum was obtained on October 9, 1999 with a 40-min exposure. There are no lines in the spectrum, and we have accordingly classified the source as a BL Lac object.

4.6. 2229+1127

The radio spectrum is a power-law at 0.408–21.7 GHz: $S = 622\nu^{-0.783}$.

The optical spectrum was obtained on October 10, 1999 with a 60-min exposure. We have identified two nearby lines separated by approximately 50 Å with the forbidden [OIII] 4959 Å and 5007 Å lines of oxygen. A weak line identified with the Hα 6563 Å line was also detected at the long-wavelength end of the spectrum. All the lines are in emission, and we have classified the object as an emission-line radio galaxy at a redshift of $z = 0.238$.

4.7. 2233+1008

The radio spectrum is complex, and the spectral index between 0.365 GHz (the Texas survey) and 0.97 GHz is $\alpha = -0.5$. If we assume that the source contains an extended component with this spectral index and subtract its contribution from the total spectrum, we obtain a spectrum that rises to 2.3 GHz and then reaches a plateau. This shape is close to the spectrum of a homogeneous, spherically symmetric source of synchrotron radio emission.

The optical spectrum, which was obtained on October 10, 1999 with a 60-min exposure, contains strong lines of carbon CIV 1549 Å and CIII] 1909 Å and a weaker magnesium MgII 2798 Å line at a redshift of $z = 1.854$. The object is a quasar.

4.8. 2300+1031

The spectrum at 0.97–21.7 GHz is well approximated by the logarithmic parabola $\log S = 0.082 + 0.868 \log \nu - 0.582 \log^2 \nu$, which has its maximum at 7 GHz. The source is absent from low-frequency surveys. The extended component in the source is weak, and the bulk of the emission comes from a compact component.

The optical spectrum was obtained on October 10, 1999 with a 60-min exposure. We identified the Lyα/NV 1216 Å 1240 Å SiIV/OIV] 1400 Å CIV 1549 Å and CIII] 1909 Å lines at a redshift of $z = 2.816$. The object is a quasar.

4.9. 2330+1218

The radio spectrum flattens toward higher frequencies. The July 2001 spectrum can be approximated by the parabola $\log S = 2.911 - 1.255 \log \nu + 0.614 \log^2 \nu$. At low frequencies, the spectrum can be divided into an extended component with a power-law spectrum with spectral index $\alpha = -0.54 \pm 0.1$ and a compact component with a rising spectrum in the range considered. The spectral index of the compact component in the initial segment is $\alpha \approx 1.8$, and the maximum occurs at 25–30 GHz.

The optical spectrum was obtained on October 6, 1999 with a 30-min exposure. We have identified three absorption lines MgI 5175 Å FeI 5270 Å and NaI 5896 Å at a redshift of $z = 0.144$. The object is an absorption-line elliptical galaxy.

5. CONCLUSION

Of the nine objects studied, five have been classified as quasars, three have redshifts $z > 2$, two are BL Lac objects, one is an absorption-line galaxy, and one is an emission-line galaxy. Table 2 summarizes some data concerning the optical and radio observations. The flux densities S at 3.9 and 7.7 GHz are given in mJy.

The columns of Table 2 present the (1) name of the object, (2) lines present in the spectrum, (3) line wavelengths in the laboratory system and as observed, (4) redshift of the object, (5) object type, (6) B magnitude of the object, (7) its flux densities at 3.9 and 7.7 GHz, and (8) the spectral index α between these frequencies.

ACKNOWLEDGMENTS

The authors thank the administration of the Guillermo Haro Observatory for support and attention to this work. This work was supported by the Russian Foundation for Basic Research (project no. 01-02-16331), the Universities of Russia Program (grant 015.02.02.19), and in part by two CONACYT grants (28499-E and J32178-E).

REFERENCES

1. A. G. Gorshkov and V. K. Konnikova, Astron. Zh. **72**, 291 (1995) [Astron. Rep. **39**, 257 (1995)].
2. A. M. Botashev, A. G. Gorshkov, V. K. Konnikova, and M. G. Mingaliev, Astron. Zh. **76**, 723 (1999) [Astron. Rep. **43**, 631 (1999)].
3. A. G. Gorshkov, V. K. Konnikova, and M. G. Mingaliev, Astron. Zh. **77**, 407 (2000) [Astron. Rep. **44**, 353 (2000)].
4. V. Chavushyan, R. Mujica, A. G. Gorshkov, *et al.*, Pis'ma Astron. Zh. **26**, 403 (2000) [Astron. Lett. **26**, 339 (2000)].

5. V. Chavushyan, R. Mujica, A. G. Gorshkov, *et al.*, Astron. Zh. **78**, 99 (2001) [Astron. Rep. **45**, 79 (2001)].
6. A. B. Berlin, A. A. Maksyasheva, N. A. Nizhel'skiĭ, *et al.*, in *Proceedings of the XXVII Radio-astronomy Conference, St. Petersburg, 1997,* Vol. 3, p. 115.
7. A. G. Gorshkov and O. I. Khromov, Astrofiz. Issled. (Izv. SAO) **14**, 15 (1981).
8. F. J. Zickgraf, I. Thiering, J. Krautter *et al.*, Astron. Astrophys., Suppl. Ser. **123**, 103 (1997).
9. I. W. A. Browne, P. N. Wilkinson, A. R. Patnaik, and J. M. Wrobel, Mon. Not. R. Astron. Soc. **293**, 257 (1998).
10. C. D. Fassnacht, S. T. Myers, T. J. Pearson, *et al.*, Astrophys. J., Suppl. Ser. **185**, 2301 (1994).
11. J. J. Condon, W. D. Cotton, E. W. Greisen, *et al.*, Astron. J. **115**, 1693 (1998).
12. D. Monet, A. Bird, B. Canzian, *et al.*, USNO-SA1.0 (Naval Observatory, Washington, DC, 1996).
13. R. L. Pennington, R. M. Humphreys, S. C. Odewahn, *et al.*, Publ. Astron. Soc. Pac. **105**, 103 (1993).

Translated by G. Rudnitskiĭ