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SOME SPECTROPHOTOMETRIC DATA FOR 31 GALAXIES FROM KARCHENTSEV'S LIST

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Abstract. The equivalent widths and relative intensities of the emission lines of 31 Karachentsev galaxies are determined on spectra obtained with a 5-m telescope incorporating a 512-channel scanner. The physical conditions in the nuclei of the galaxies are analysed and the relative oxygen content is defined. The parameters derived are compared to similar parameters of Seyfert, Arakelian, and Markarian galaxies.

1. Introduction

Karachentsev's (1972) *Catalog of Double Galaxies* includes 603 double systems. In recent years the radial velocities of the galaxies have been defined and the mass determinations of the components for 440 galaxies have been derived. With very few exceptions spectrophotometric data for double galaxies are not available. We carried out a detailed spectrophotometry covering the red spectrum along the Hα line on spectra with a dispersion of 100–200 Å mm^{-1} (a resolution of 5–10 Å) for the following galaxies: Karachentsev 288a, b (Petrov *et al.*, 1981), Karachentsev 466a = NGC 5929 (Yankulova *et al.*, 1980), Karachentsev 570b = NGC 7339 (Petrov *et al.*, 1984), and Karachentsev 578a = NGC 7537 (Petrov *et al.*, 1983).

2. Observations and Results

In this communication we present spectrophotometric data for 31 galaxies from the list of Karachentsev (1972). The observational material, which Karachentsev kindly placed at our disposal, includes about 100 scans in the region of $\lambda\lambda$3700–5300 Å obtained with the 5-m Hale telescope of the Mount Palomar Observatory, incorporating a 512-channel scanner. The spectral resolution is about 4 Å per channel. In all cases the slit of the spectrograph is aligned along the right ascension. By applying the standard methods we have determined the equivalent widths and relative intensities of the emission lines. The data are listed in Table I. The table includes the reference number according to Karachentsev (1972) (column 1), another designation (column 2), $W_\lambda 3727$ (column 3), $W_{\mathrm{H}\gamma}$ (column 4), $W_{\mathrm{H}\beta}$ (column 5), $W_\lambda 4959$ (column 6), $W_\lambda 5007$ (column 7) and the relative intensities of the same lines with reference to $I_\lambda 5007 = 1.00$ (columns 8–11). To obtain the continuous spectrum, several iterations have been made in order to bring the $I_\lambda 4959/I_\lambda 5007$ ratio to the theoretical one.

Except for Kar 97a, the galaxies studied in this paper have weak emission lines. The [O III] λ4363 line is not apparent. Thus we are not able to make a simple determination

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of the electron density and electron temperature in the emission regions. It is possible, however, to estimate the electron density by applying the method suggested more than 25 years ago by Minkowski and Osterbrock (1959) for the analysis of the gas content in elliptical galaxies. The method in short consists of the following: The $\lambda 3737$ [O II] line, which is often observed in the galaxies, is in fact a doublet of two close lines ($\lambda 3726.06$ Å and $\lambda 3728.80$ Å). Due to the Doppler line broadening resulting from the chaotic movement of gas clouds emitting these lines, they merge into a wide blend.

If we assume that the observed wavelength of the blend 3727 Å is the mean weighted of the intensities of the individual components, then

$$\langle \lambda \rangle = \frac{3726.05 + 3728.80r}{1 + r} \quad \text{where} \quad r = \frac{I_\lambda 3728.80}{I_\lambda 3726.05} . \tag{1}$$

For different Ne and Te the r ratio is tabulated by Saraph and Seaton (1975).

Then the measured radial velocity will be

$$\Delta V = \frac{\langle \lambda \rangle - 3727.00}{3727.00} c = \frac{-0.95 + 1.80r}{1 + r} \frac{c}{3727.00} . \tag{2}$$

For reasonable values of Ne (10^2–10^5 cm^{-3}) and Te (5×10^3–2×10^4 K) which are typical of PlN, galactic nuclei and the like, r varies from 0.34 to 1.4 (Osterbrock, 1974). If calculated in terms of radial velocity difference, it will correspond to $\Delta V = -20$ to $+55$ km s^{-1}. Hence, the greatest difficulty in the application of this method is to obtain an insignificant error in the determination of radial velocities.

Karachentsev *et al.* (1979) determined the radial velocities for 44 double galaxies, 31 of which are included in this work. The mean error in the radial velocity determinations for these objects is ± 31 km s^{-1}. This permitted the analysis of the electron density of the emittive gas by applying the method described above. Table II lists the measured radial velocities of the doublet $\lambda 3727$ (column 3), the mean radial velocity along Hβ, N_1 and N_2 lines (column 3), the difference in the measured radial velocities (column 4) and the mean error σ_y in the determination of the radial velocities (column 5). For 15 objects, Hγ line has also been measured.

It is worth noting that the electron density Ne in Karachentsev 97a is very high. For all the rest of the objects, Ne is of the order of 10^2 cm^{-3}.

The measured radial velocities, equivalent emission line widths and determined electron gas density in the galaxies permit the determination of the physical conditions in regions emitting forbidden lines. The method was described in detail by Dibai and Pronik (1965) and was applied in the study of SyG NGC 1068.

The luminosity in Hβ–$L_{\mathrm{H}\beta}$ at Te = 10^4 K and H = 75 km s^{-1} Mpc^{-1} is

$$L_{\mathrm{H}\beta} = 2.12 \times 10^{46} \, V_r^2 F_{\mathrm{H}\beta} \, \mathrm{erg\,s^{-1}} ,$$

where V_r is the radial velocity in km s^{-1} and $F_{\mathrm{H}\beta}$ is the luminous flux in Hβ in erg cm^{-2} s^{-1} defined with reference to the equivalent $W_{\mathrm{H}\beta}$ of Hβ and the magnitude of the galaxy m_p. Since the slit of the spectrograph was 0″.9 × 60″, no corrections for the magnitude of the galaxy have been made.

TABLE I

Equivalent widths, relative intensities of the emission lines and oxygen content in 30 galaxies of Karachentsev's list

Kar No.	Other names	$W_\lambda 3727$	$W_{H\gamma}$	$W_{H\beta}$	$W_\lambda 4959$	$W_\lambda 5007$	$\frac{I_\lambda 3727}{I_\lambda 5007}$	$\frac{I_\lambda H\gamma}{I_\lambda 5007}$	$\frac{I_\lambda H\beta}{I_\lambda 5007}$	$\frac{I_\lambda 4959}{I_\lambda 5007}$	m_p	$\log O^+$	$\log O^{++}$	$\log O$
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
9a				1.6	2.7	8.4			0.22	0.34	15.5		8.16	
9b		5.3		1.0	0.5	1.4	2.2		0.70	0.35	15.5	8.46	7.66	8.52
19b	NGC 317b			0.8		0.7			1.10		14.5		7.48	
34a	NGC 569	2.7		0.5		0.5	2.7		1.07		14.7	8.36	7.47	8.41
34b		6.0		0.6	0.6	1.7	2.1		0.36	0.34	15.7	8.36	7.94	8.50
47b	VV 122	1.6		1.0		1.3	0.8		0.78		14.7	7.97	7.60	8.12
50	NGC 786ab	3.0		0.7		0.3	6.5		3.00		14.3	8.30	7.02	8.32
67b	VZW 233	2.0		0.5		1.0	1.2		0.55		14.9	8.31	7.76	8.42
70a	IC 1817a	2.0	1.2	1.7		1.8	0.8	0.7	0.97		15.6	7.89	7.51	8.04
70b	IC 1817b			2.0		5.2			0.46		15.6		7.84	
82a		2.8	0.5	2.3	0.4	1.4	1.4	0.4	1.80	0.33	15.3	7.86	7.25	7.96
93b	VV 729		1.2	0.8	1.9	5.3		0.2	0.11	0.36	15.4		8.45	
97a	NGC 1507a	8.0	2.0	14.5	17.0	50.6	0.1		0.28	0.33	13.8	7.20	8.06	8.12
97b	NGC 1507b		1.0	5.8	7.1	21.3			0.27	0.33	13.8		8.06	
119		6.0	0.5	1.5	1.4	4.5	1.1	0.1	0.33	0.32	15.0	8.48	7.98	8.60
124a		4.0		0.4	0.7	2.0	1.2		0.21	0.33	15.4	8.70	8.18	8.81
124b		4.6	0.2	0.8	0.4	1.4	1.7	0.2	0.67	0.32	15.4	8.42	7.72	8.50
130a		5.2	0.8	1.7	1.0	2.7	1.2	0.3	0.67	0.37	15.6	8.23	7.68	8.34
137a		6.0	0.8	2.9	2.7	8.2	0.5	0.1	0.38	0.34	15.5	8.05	7.92	8.29
137b	VV 539	5.5	1.4	4.5	4.1	11.0	0.4	0.1	0.43	0.39	15.5	7.90	7.86	8.18
155b	IC 2229	6.5	0.9	1.8	1.4	4.1	1.2	0.2	0.48	0.36	15.4	8.37	7.82	8.48
160b		4.1		0.7		1.0	1.8		0.72		15.5	7.97	7.64	8.14
506a	VV 89	4.2	0.9	3.1	5.7	16.3	0.3	0.1	0.19	0.35	15.0	8.09	8.23	8.47
506b				1.7		2.7			0.63		15.0		7.70	
526a	NGC 6500	28.5	2.5	5.6	2.7	7.2	1.6		0.77		13.4	8.28	7.61	8.36
535b	VV 569			2.7	1.9	5.9			0.54	0.35	15.3		7.77	
538b				3.1	4.8	13.3			0.23		15.1		8.13	
579b	Ho 807	3.0		3.3	1.5	4.4	0.4		0.76		15.0	7.64	7.62	7.93
598a	VV 255	8.0	0.7	4.0	3.6	11.2	0.7	0.05	0.36	0.32	15.2	8.26	7.95	8.43
600b				4.0		0.7	3.4		0.90		15.5	8.53	7.54	8.57

47b = Arp 126; 93b = III Zw 55; 506a, b = Arp 32; 598a = Arp 262.

TABLE II

Parameters of the gaseous component in the nuclei of 32 Karachentsev galaxies

Kar No.	V_r (3727)	$\overline{V}_r$ (Hβ, N$_1$, N$_2$)	$V_r - \overline{V}_r$	σ_V	Ne [cm^{-3}]	Ne max–min	$L_{H\beta}$ [erg s^{-1}]	V_{eff} [cm^3]	M_{gas} [$M_\odot$]	N_*	$\frac{M_{gas}}{M_{gal}}$
1	2	3	4	5	6	7	8	9	10	11	12
9a	5400	4890	210	22	100		6.08×10^{38}	4.91×10^{59}	40760	200	1.56×10^{-5}
9b	5220	4950	270	31	100		3.90×10^{38}	3.14×10^{59}	26100	130	1.00×10^{-5}
19b	5220	4740	480	30	100		4.40×10^{38}	3.55×10^{59}	29500	150	1.61×10^{-7}
34a	5760	5430	330	20	400	2500–100	3.31×10^{38}	4.27×10^{56}	900	110	1.85×10^{-6}
							3.31×10^{38}	1.67×10^{58}	5550	110	1.15×10^{-5}
							3.31×10^{38}	2.67×10^{59}	22180	110	4.62×10^{-5}
34b	5520	5480	40	30	100		2.63×10^{38}	2.12×10^{59}	17600	88	3.67×10^{-5}
47b	5520	5325	195	27	100		6.37×10^{38}	5.14×10^{59}	42670	210	2.03×10^{-6}
50	4680	4320	360	49	100		4.09×10^{38}	3.30×10^{59}	27420	140	
67b	9750	9540	210	10	100		9.37×10^{38}	7.56×10^{59}	62810	320	2.42×10^{-6}
70a	7290	6979	311	17	100		1.26×10^{39}	1.01×10^{60}	84260	420	1.40×10^{-5}
82a	9000	8755	245	37	100		3.06×10^{39}	2.47×10^{60}	204740	1030	2.15×10^{-6}
97a	8100	8925	–825	20	10^6	10^6–100	3.83×10^{40}	3.03×10^{53}	260	12860	2.50×10^{-8}
97b	10500	9375	1125	22	100		1.69×10^{40}	1.36×10^{61}	1131400	5670	1.10×10^{-4}
119	5370	4675	695	39	100		6.47×10^{38}	5.22×10^{59}	43350	220	1.60×10^{-6}
124a	6300	5910	390	26	100		2.32×10^{38}	1.87×10^{59}	15540	80	1.81×10^{-7}
124b	6000	5805	195	15	100		4.48×10^{38}	3.61×10^{59}	29980	150	3.49×10^{-7}
130a	6780	6540	240	14	100		1.12×10^{39}	8.94×10^{59}	74180	370	
137a	3810	3520	290	27	100		5.71×10^{38}	4.61×10^{59}	38280	190	1.29×10^{-6}
137b	3900	3590	310	20	100		9.22×10^{38}	7.44×10^{59}	61780	310	2.09×10^{-6}
155b	7470	7015	455	28	100		1.47×10^{39}	1.19×10^{60}	98520	495	1.45×10^{-5}
160b	3420	3405	15	32	2250	56250	1.29×10^{38}	3.44×10^{53}	20	50	4.68×10^{-12}
						–140	1.29×10^{38}	2.06×10^{56}	380	50	1.12×10^{-10}
							1.29×10^{38}	5.31×10^{38}	6180	50	1.81×10^{-9}

Table II (continued)

Kar No.	V_r (3727)	$\bar{V}_r$ (Hβ, N_1, N_2)	$V_r - \bar{V}_r$	σ_V	Ne [cm^{-3}]	Ne max–min	$L_{H\beta}$ [erg s^{-1}]	V_{eff} [cm^3]	M_{gas} [$M_\odot$]	N_*	$\frac{M_{gas}}{M_{gal}}$
1	2	3	4	5	6	7	8	9	10	11	12
506a	1440	1090	350	27	100		7.27×10^{37}	5.86×10^{58}	4870	20	1.62×10^{-7}
506b	1050	960	90	74	100	1800–100	3.09×10^{37}	7.70×10^{55}	120	10	
							3.09×10^{37}	2.49×10^{58}	2070	10	6.90×10^{-8}
526a	3.270	2830	440	32	100		1.76×10^{39}	1.42×10^{60}	118300	590	1.40×10^{-6}
579b	9750	9520	230	56	100		5.90×10^{39}	4.76×10^{60}	395370	1980	1.11×10^{-6}
598a	1830	1650	180	22	100		1.97×10^{38}	1.59×10^{59}	13200	70	5.74×10^{-7}
600b	6930	6690	240	36	100		4.27×10^{38}	3.44×10^{59}	28600	140	2.07×10^{-6}
29a	14100	13200	900	111	100						
47b	5400	5250	150	27	100						
67a	9600	9600	0	10	4500	14100–2800					
83b	8400	8400	0	80	4500	10^6–100					
130b	6900	6600	300	10	100						
515b	6540	6530	10	56	400	56250–100					

TABLE III

Mean oxygen ion content in different types of emission objects

Type of object	Sy1G	BLRG	Sy2G	NLRG	Double galaxies	Galactic H II regions	MC H II regions
logO^+	5.87 (35)	7.65 (17)	8.02 (21)	7.35 (14)	8.16 (22)	8.12 (27)	7.88 (13)
logO^{++}	7.29 (35)	7.75 (17)	8.11 (23)	7.72 (15)	7.79 (30)	–	–
logO	7.31 (35)	8.00 (17)	8.37 (21)	7.87 (14)	8.34 (22)	–	–

The effective volume of gas is defined by the expression $V_{\text{eff}} = 8.07 \times \times 10^{24} L_{\text{H}\beta} \text{Ne}^{-2}$ (cm^3) on the assumption that the number of free electrons is equal to that of the protons.

The mass of ionized gas in solar units is derived by

$$M_{\text{gas}} = 6.70 \times 10^{-33} L_{\text{H}\beta} \text{Ne} \, [M_\odot] \, .$$

If we assume that the gas is in a ionizing-recombination balance and that the ionization is due to the ultraviolet emission of young hot stars, it will be possible to estimate their number. According to the function of star formation of Schmidt (1963), the mean spectral class of stars from O5 to B0.5 is O7, the mean mass of every star being 30 $M_\odot$. Then $N_* = 3.36 \times 10^{-37} L_{\text{H}\beta}$ is the number of stars required for the explanation of the observed flux in Hβ. The estimates are listed in columns 7 to 10 of Table II.

A method of determinig the ion content and chemical composition of the emitting gas has been suggested by Peimbert (1968). He applied the method in the analysis of M51 and M81 galaxies.

For the ions of the O$^+$ and O^{++} oxygen, we have, respectively,

$$\frac{\text{O}^+}{\text{H}^+} = 2.57 \times 10^{-5} \left[\frac{1 + 7.6x + 6.8x^2}{1 + 5.6x} \right] \text{Te}^{-0.375} \, \frac{I_\lambda 3727}{I_{\text{H}\beta}} \, 1 \, \frac{3.86 \times 10^4}{\text{Te}}$$

and

$$\frac{\text{O}^{++}}{\text{H}^+} = 5.55 \times 10^{-5} [1 + 0.01x] \text{Te}^{-0.375} \, \frac{I_\lambda 5007}{I_{\text{H}\beta}} \, 1 \, \frac{2.89 \times 10^4}{\text{Te}} \, ,$$

where

$$x = 10^{-2} \, \text{Ne} \, \text{Te}^{-1/2} \quad \text{and} \quad \frac{\text{O}}{\text{H}} = \frac{\text{O}^+ + \text{O}^{++}}{\text{H}^+} \, .$$

The ion and oxygen atom content for Te = 10000 K is tabulated in columns 13, 14, and 15 of Table I. Generally $\log H = 12.00$ is adopted.

3. Discussion

The studied sample of double galaxies includes only one active object, Kar 93b = III Zw 55, which is a Seyfert galaxy of the NGC 1068 type. Koski (1978) presented some spectrophotometric data for this galaxy. The comparison between those data and the data obtained by us gives an idea of the accuracy of the results. The data obtained in our work and those obtained by Koski (in brackets) are presented below:

$$\log F_{\text{H}\beta} = 2.51 \times 10^{-15} \, \text{erg cm}^{-2} \, \text{s}^{-1} \quad (4.1 \times 10^{-15}) \, ,$$

$$\frac{I_\lambda 4959 + I_\lambda 5007}{I_{\text{H}\beta}} = 12.3 \quad (9.28) \, ,$$

$$\log \text{O}^{++} = 8.45 \quad (8.34) \, .$$

Note that Koski determined the total intensity of N_1 and N_2 with reference to Hβ because of the lower spectral resolution.

The evaluations of electron density in double galaxies show that the gaseous medium is very rarefied except for the galaxy Kar 97a = NGC 1057a where the electron density is about critical and forbidden lines can still be observed. The case with Kar 83b is similar. Arakelian *et al.* (1975) referred Kar 67a to SyG but Karachentsev *et al.* (1979) rejected this statement. The electron density in this galaxy is 10^3–10^4 cm^{-3} which is typical of [O II] regions in SyG and PlN. The mean electron density determined with regard to the doublet 6717, 6731 of the ionized sulphur for various types of emission objects (Petrov, 1980) is 10^3 cm^{-3}. As in the galaxies studied, such a low mean density is typical only of H II regions of Magellanic Clouds. On the other hand, the lumiunosities in the Hβ line are 10^{38}–10^{40} erg s^{-1}. This is why the mass determinations of the emittive gas are high (10^4–10^5 $M_\odot$) in the mean. Particularly strong is the difference in the physical properties of the gas in the components of Kar 97: with a nearly equal luminosity $L_{\mathrm{H}\beta}$, the mass of the gas in component 97a is approximately 250 $M_\odot$, while in 97b it excels 10^6 $M_\odot$. Column 11 of Table II shows the $M_{\mathrm{gas}}/M_{\mathrm{gal}}$ ratio (the relative ionized gas content) as determined by us. Except for Kar 130a and Kar 600, all the rest are spiral galaxies. The low ionized gas content indicates a weak ionizing field – only for four galaxies (Kar 82a, 97a, b, and 579b) is the required number of ionizing stars 1000–10000. For all the rest of the cases, tens to hundreds of hot stars are sufficient.

The double galaxies that were studied are very rich in oxygen. The relative oxygen content is as in Sy2 galaxies, but naturally the relative content of O^{++} is lower than in double galaxies, while the content of O^+ is higher. Table III lists the mean oxygen ion and atom content in various types of emission objects. The number of objects studied is given in brackets.

In conclusion we should point out that the sample of 30 galaxies is not sufficiently representative of all 603 pairs, but the derived determinations for the basic physical parameters, however, permit the final consideration that duplicity yields some characteristic changes in the objects, i.e. a large volume of gas with low density and considerable mass, a relatively high degree of excitation (e.g., Markarian and Arakelian galaxies generally heave weaker O^{++} lines) and oxygen content. The last is of particular importance provided that oxygen is a very good cooling agent.

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