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Group of galaxies around the giant radio galaxy 4C 73.08

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ABSTRACT

The optical field of the giant radio galaxy (GRG) 4C 73.08 has been spectroscopically investigated to look for companions to the host 7Zw 292. We have taken spectra of 12 candidates and have determined redshifts for all of them. When combined with the previously known redshift of 7Zw 292, we find that the radio source is accompanied by a small group of nine galaxies, of which the GRG host is the brightest. Seven members of the group lie within 350 kpc of 7Zw 292, gathered around the brighter, more compact component of the double radio source. The whole group has a velocity dispersion of $\sim$270 km s^{-1}. We discuss this result in the light of the X-ray emission which has been detected from the region. 4C 73.08 follows the pattern found in other GRGs of being associated with a small group, but not falling in a rich cluster.

Key words: techniques: spectroscopic – ISM: jets and outflows – galaxies: active – galaxies: distances and redshifts – galaxies: individual: 4C 73.08 – galaxies: ISM.

1 INTRODUCTION

Giant radio galaxies (GRGs) are the largest known objects with linear sizes greater than 1 Mpc (Klein et al. 1994). Since their discovery in 1974 (Willis, Strom & Wilson 1974), many GRGs have been found and studied in detail. It is generally accepted that their lobes move outwards through the low-density (10^{-5} to 10^{-6} cm^{-3}) intergalactic medium (IGM), with estimated spectral ages of 10^7–10^8 yr. The radio galaxy 4C 73.08 with an uncommon double-cross morphology was first studied by Mayer (1979), who identified it as a source of large angular diameter from Sixth Cambridge Survey of radio sources (6C) survey data. Mayer mapped the source at several frequencies, provided radio spectra of the emission and noted its likely association with a compact galaxy, 7Zw 292, at a redshift of 0.0581 (Demoulin 1970).

Jägers (1986) mapped 4C 73.08 at three frequencies (0.3, 0.6 and 1.4 GHz) in total intensity and linear polarization, determined important physical parameters and noted the likely presence of companions to 7Zw 292. 4C 73.08 is one of the GRGs included in the sample of such objects constructed by Schoenmakers et al. (2000). They have, for the entire sample, extracted the main parameters which can be derived from radio observations. The radio source's total extent of about 19 arcmin at the distance of 7Zw 292 implies a projected linear size of about 1.2 Mpc (for $H_0 = 75$ km s^{-1} Mpc^{-1}). X-ray emission associated with 4C 73.08 has been reported by Evans et al. (2008).

Galaxies around GRGs have been previously studied to examine the influence of the surrounding IGM on the evolution of the radio morphology. We have done this for DA 240 (Peng et al. 2004; Chen et al. 2011b), NGC 6251 (Chen et al. 2011a) and NGC 315 (Chen et al. 2011c), and it has been done by others for MSH 05−022 (Subrahmanyan et al. 2008) and MRC B0319−454 (Safouris et al. 2009). The possibility that the host galaxy of 4C 73.08 might belong to a group was first raised by Caswell (1966) and later discussed by others (Mayer 1979; Jägers 1986). To investigate the matter further, we have made spectroscopic observations of objects (brighter than 16 mag) within a 20-arcmin arc radius with the 2.16-m optical telescope at XingLong Station of National Astronomical Observatories, Chinese Academy of Sciences (NAOC).

The paper is organized as follows: we consider selection of the optical sample in Section 2.1, the observations in Section 2.2 and their reduction in Section 2.3. The results of the spectroscopy are presented in Section 3. We draw a number of conclusions in Section 4. Throughout, we adopt a flat cosmology with matter density $\Omega_m = 0.27$, energy density $\Omega_\Lambda = 0.73$ and Hubble constant $H_0 = 75$ km s^{-1} Mpc^{-1}.

2 OBSERVATIONS AND DATA REDUCTION

New observations were made at both optical and radio wavelengths. The 21-cm radio observations show the same general structures as

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Table 1. 12 selected candidate galaxies with magnitudes brighter than 16^m in the *R* band and six galaxies with published redshifts *z*.

No.	RA (J2000) ($^h\,^m\,^s$)	Dec. (J2000) ($^\circ\,'\,''$)	*R* (app.mag)	Redshift (*z*)
1	09 47 15.8	72 59 10	11.0	0.022 999[a]
2	09 47 18.0	72 59 03	16.0	0.022 856[b]
3	09 47 22.5	73 12 19	15.1	
4	09 47 50.4	72 57 52	9.6	0.021 808[b]
5	09 48 26.8	72 57 19	12.4	
6	09 48 40.3	73 13 24	14.4	
7	09 49 30.7	73 33 39	13.8	
8	09 49 37.9	73 33 19	14.8	
9	09 49 45.8	73 14 23	11.7	0.0581[c]
10	09 49 48.9	73 13 18	13.2	
11	09 49 51.4	73 10 40	14.6	
12	09 49 55.4	73 14 35	13.9	
13	09 50 00.4	73 14 09	12.8	
14	09 50 06.8	73 12 20	13.5	
15	09 50 52.4	73 18 59	14.9	
16	09 51 06.2	73 02 49	18.6	0.387[d]
17	09 51 13.7	73 18 35	18.2	0.251[d]
18	09 51 56.9	73 15 34	15.7	

Redshifts are taken from the following. [a]NED Team (1992); [b]De Vaucouleurs et al. (1991); [c]Hewitt & Burbidge (1991); [d]Puchnarewicz et al. (1997).

the maps in the thesis of Jägers (1986). They are presented and discussed in detail in a companion paper. Here the radio data are only used to set the context for our study of the group of galaxies.

2.1 Sample selection

We have searched for galaxies within a radius of about 20 arcmin (set by the linear size of the source and available observing time) from the 4C 73.08 nucleus. With six galaxies of known redshift from the literature, 12 candidates of unknown redshift brighter than ∼16 mag in the *R* band were found, which are all listed in Table 1. Each source is numbered in order of its right ascension (RA) and there follows the source coordinates (RA and Dec. for J2000 epoch), apparent *R*-band magnitude and redshift (*z*) with reference if known, in columns 2–5, respectively. The apparent magnitudes were taken from the United States Naval Observatory (USNO)-A 2.0 catalogue.

2.2 Observations

In order to determine redshifts of the selected candidates, spectroscopic observations were made with the 2.16-m optical telescope and Optomechanics Research (OMR) spectrograph of Xinglong Station, NAOC, using a SPEC10 1340 × 400 CCD as detector in 2011 January. A 300 g mm^{-1} grism and 2.5-arcsec-wide slit were used to get a wavelength coverage of 3800–8000 Å with an average spectral resolution of 4.8 Å. Exposures of 3600 s were taken on the four nights of January 28–31 in 2011. The wavelength calibrations were made with helium and argon lamps, and the flux calibration was provided by exposures of the Kitt Peak National Observatory (KPNO) standard stars (Massey et al. 1988), such as Feige34, HD19445, etc. The atmospheric extinction was corrected for the mean extinction of Xinglong Station, and the telluric O_2 absorption bands at 6870 and 7620 Å were not removed.

2.3 Data reduction

The spectral data were reduced with IRAF[1] software. After the wavelength and flux calibration, each spectrum was inspected for emission and/or absorption features. When at least two spectral lines could be identified, the average redshift (*z*) was determined, and the error was also estimated. The reduced spectra can be found in Appendix A, also in order of RA.

The redshifts we obtained are listed in the fifth column of Table 2, while the spectral lines identified are given in the sixth column. We made simple classifications of the objects observed, following the criteria of Veilleux & Osterbrock (1987). Galaxies without emission lines are classified as normal (G), while objects with Hα emission but weak forbidden lines of [N II] 6583 Å and [O III] 5007 Å are classified as H II.

3 RESULTS AND DISCUSSION

We observed all 12 selected candidates and successfully determined their redshifts, none of which has been published before. All results are listed in Table 2, in which columns 1–7 are the serial number used in Table 1, the RA+Dec. name, common name, observing date, redshift, spectral lines identified and classification of galaxy type, respectively. Redshifts taken from published papers (see Table 1) are enclosed in brackets.

There is an obvious concentration around $z \sim 0.058$, as shown in the histogram of Fig. 1. The nine galaxies in the redshift range between 0.057 and 0.060 are considered group members, as all pass the (3σ) velocity dispersion test suggested by Yahil & Vidal (1977). This confirms the suggested 7Zw 292 group of Mayer (1979) and Jägers (1986). Three galaxies with $z \sim 0.022$ are in the foreground, while the remaining six belong to the background.

The magnitudes of the nine group members are indicated by a solid line in the histogram of Fig. 2, which shows a symmetric distribution around the peak of 14 mag. The host galaxy of 4C 73.08 is the brightest member of the group. The cut-off for $m >$ 16 is due to the limited sensitivity of the 2.16-m telescope, and four unobserved candidates fainter than 16 mag are marked by a dotted line. However, there could be more faint galaxies in the region which may be turned up by future deeper surveys or observations at other wavelengths.

Positions of all 18 galaxies are shown on the radio map (Fig. 3). The three foreground galaxies (nos 1, 2 and 4) marked by boxes lie to the southwest of the radio galaxy and form a small group. The background galaxies are indicated by triangles. They include a pair (nos 7 and 8), one of which (7) appears to be a double radio source. The 7Zw 292 group members are marked with crosses, while the host is highlighted by a five-pointed star. They are clustered about the Sp component of the radio galaxy 4C 73.08. The nine members are in a quite asymmetric distribution. All of them lie in the southwestern part of the radio map, most around the brighter southwest radio lobe, though nos 3 and 5 are somewhat removed from the host, which is obvious in the distance distribution (Fig. 4): most members are within 350 kpc of the host, while nos 3 and 5 are 650 and 1045 kpc from it.

Not considering uncertainties in the measurements, we note that the relative velocities of the group members tend to lie at the high end, where the host is used as the reference point (Fig. 5). This

[1] Image Reduction and Analysis Facility.

Table 2. Summary of all results. 12 candidates observed with the 2.16-m optical telescope and six additional ones from other sources like NED (observing dates left blank, z enclosed in brackets).

No.	RA+Dec. name (J2000)	Common name	Obs. dates (yyyy.mm.dd)	Redshift (z)	Notes	C
1	094715+725910	NGC 2957_01	–	(0.022 999)	–	–
2	094718+725903	NGC 2957_02	–	(0.022 856)	–	–
3	094722+731219		2011.01.30	0.0598 ± 0.0004	Na D, Hα, [N II]	H II
4	094750+725752	NGC 2963	–	(0.021 808)	–	–
5	094826+725719	MCG+12-10-004	2011.01.28	0.0587 ± 0.0006	Mg B, Hα, [N II]	H II
6	094840+731324		2011.01.29	0.0580 ± 0.0001	Mg B, Na D	G
7	094930+733339		2011.01.29	0.0827 ± 0.0006	[O III], Na D, Hα	H II
8	094937+733319		2011.01.30	0.0828 ± 0.0005	*G* band, Mg B, Fe E, Na D	G
9	094945+731423	7Zw 292	–	(0.0581)	–	–
10	094948+731318		2011.01.28	0.0575 ± 0.0008	Mg B, Fe E, Na D	G
11	094951+731040		2011.01.29	0.0581 ± 0.0003	Hα, [N II]	H II
12	094955+731435		2011.01.30	0.0600 ± 0.0003	*G* band, Mg B, Fe E, Na D, Hα	G
13	095000+731409		2011.01.28	0.0592 ± 0.0009	*G* band, Na D, Hα, [N II]	H II
14	095006+731220		2011.01.29	0.0574 ± 0.0009	*G* band, Mg B, Fe E, Na D	G
15	095052+731859		2011.01.31	0.1282 ± 0.0011	Mg B, Na D, Hα, [N II]	H II
16	095106+730249	RIXOS F305_018	–	(0.387)	–	–
17	095113+731835	RIXOS F305_011	–	(0.251)	–	–
18	095156+731534		2011.01.30	0.0690 ± 0.0004	Na D, Hα, [N II]	H II

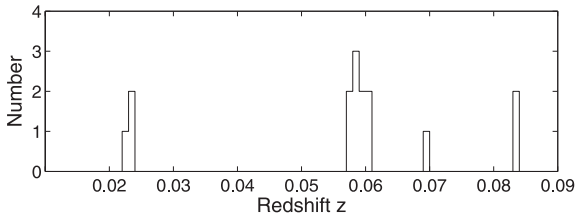

Figure 1. Histogram of the redshift distribution for the 18 galaxies from Table 2. The highest peak near $z = 0.06$ is due to members of the 4C 73.08 group.

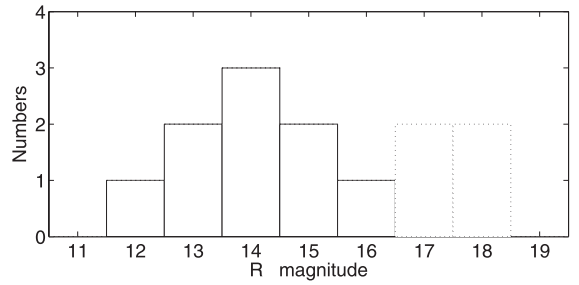

Figure 2. A histogram showing the *R*-band magnitudes of the group of galaxies we have studied (Tables 1 and 2) traced with a solid line, while a dotted line gives the magnitudes of the four unobserved USNO galaxies.

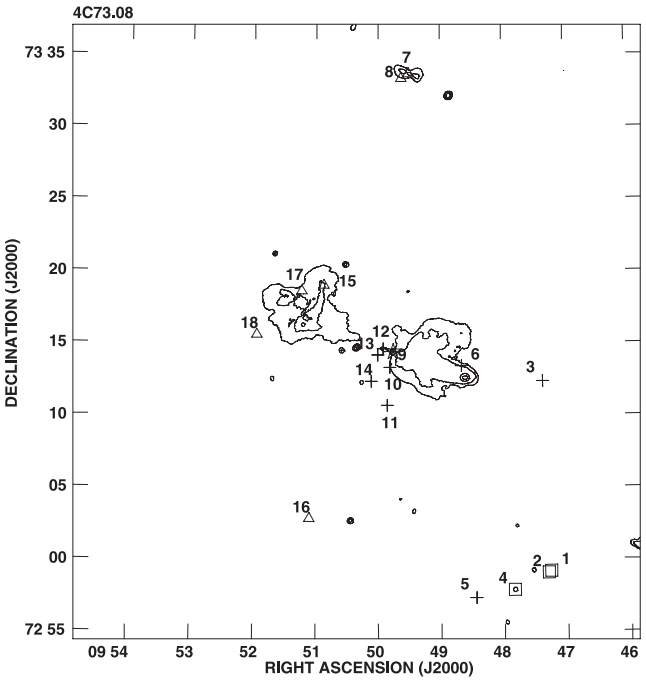

Figure 3. Contour plot of the radio brightness, with optical galaxies from Table 2 marked. A five-pointed star indicates the host, while its companions in the group are shown by crosses. Foreground galaxies are marked by squares and background objects by triangles. Radio contours are drawn at 0.9, 3.4, 13.7 and 54.7 mJy beam^{-1}.

may be a genuine asymmetry, or there could be more members of the group we have missed. The velocity dispersion of the group is 269 km s^{-1}, and we can derive an expected X-ray luminosity of 1.9×10^{42} erg s^{-1} from the correlation between velocity dispersion and X-ray luminosity (Mulchaey & Zabuldoff 1998). The X-ray spectrum of 4C 73.08 has been modelled as a combination of a heavily absorbed power law associated with a luminous accretion disc and circumnuclear obscuring structure ($L_{x1} \sim 5.0 \times 10^{43}$ erg s^{-1}), together with an unabsorbed component of X-ray emission from the unresolved jet ($L_{x2} \sim 3.3 \times 10^{41}$ erg s^{-1}) (Evans et al. 2008). However, nothing is said about an extended thermal component, which may be because the observation was affected by flaring.

4 CONCLUSIONS

In the continuing research following our study of the GRGs DA 240, NGC 6251 and NGC 315, we have made spectroscopic observations of galaxy candidates brighter than 16 mag in the *R* band

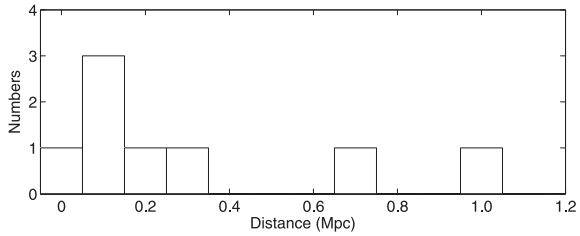

Figure 4. Relative distance distribution of the eight group galaxies from the GRG host 7Zw 292.

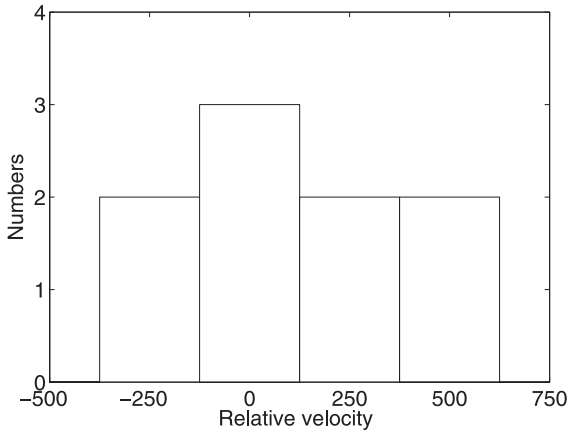

Figure 5. Relative velocity distribution of the nine members of the 4C 73.08 group. The zero-point is the systemic velocity of the host galaxy.

within 20 arcmin arc radius of the 4C 73.08 nucleus. 12 spectra and redshifts have been determined for candidates on our list, and a galaxy group of nine members (including the host) around 4C 73.08 has for the first time been identified. In the case of the radio galaxies NGC 6251 and NGC 315, the X-ray luminosity expected from the $L_{\rm x}$–σ_r relationship was found to be higher than the observed value. However, published X-ray observations of 4C 73.08 (Evans et al. 2008) are insufficiently sensitive to meaningfully test whether it conforms to the same pattern. The fact that its group is clustered around the brighter, more compact Sp lobe is consistent with the ambient gas density tracing the galaxy density, as we have also seen in NGC 315 (Chen et al. 2011c) and NGC 6251 (Chen et al. 2011a).

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APPENDIX A: SPECTRA OF GALAXIES

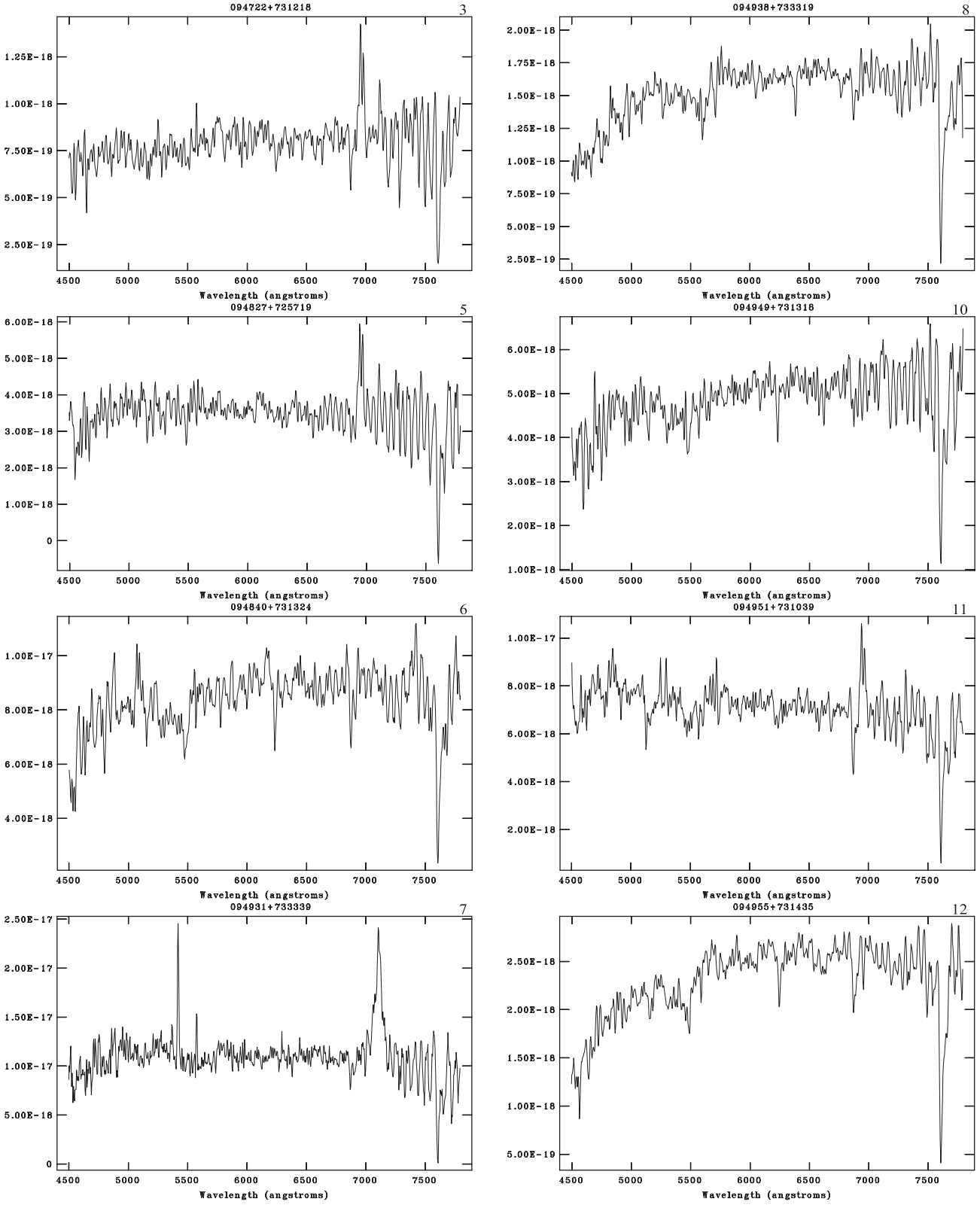

Figure A1. Spectra of the 12 galaxies around 4C 73.08, observed with the 2.16-m optical telescope at Xinglong Station of the NAOC.

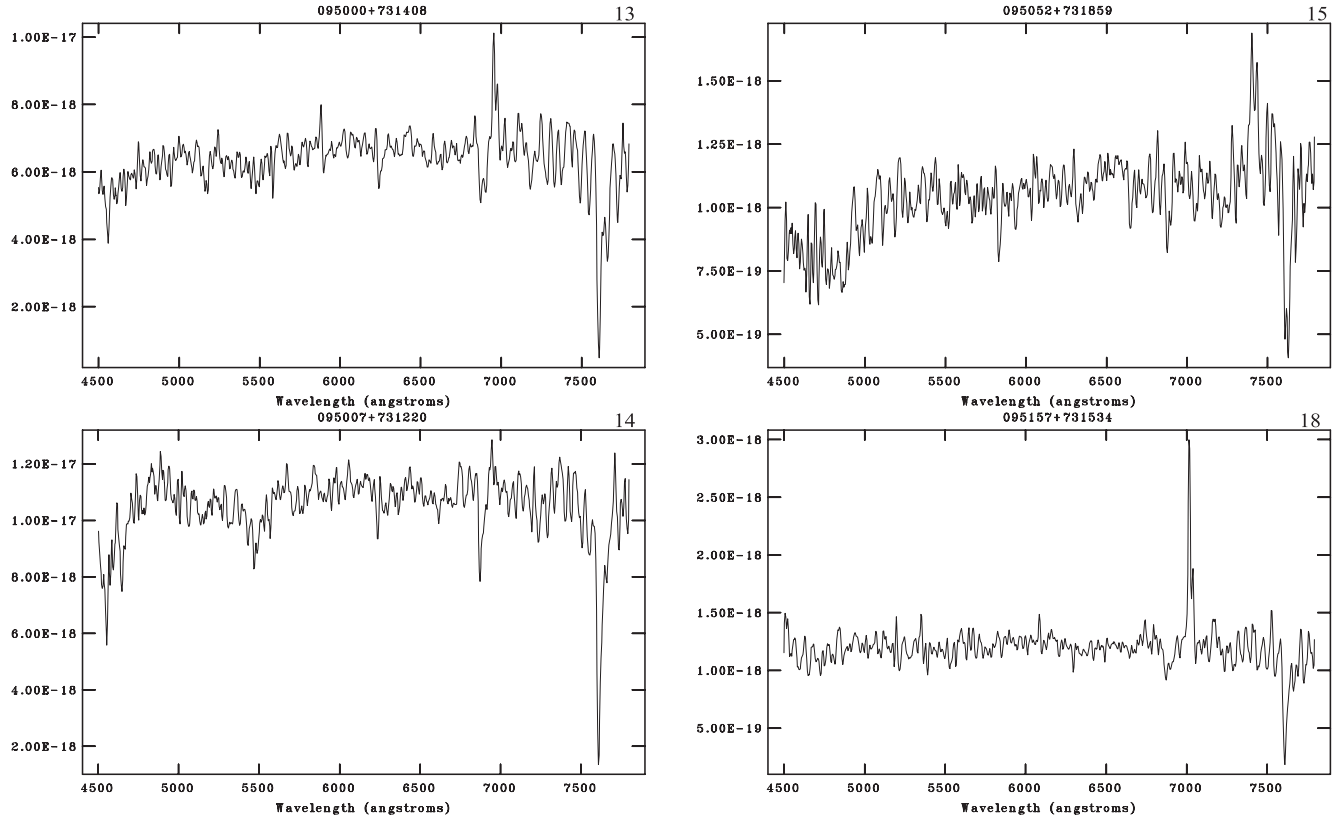

Figure A1 – *continued*

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