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VRI Photometry of Stars in the Fields of 16 Blazars

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ABSTRACT. We present a list of photometric *VRI* comparison sequences in the fields of 16 blazars. For six of these objects, comparison stars were calibrated for the first time during the present work. For most of the other 10 blazars, we improved the old sequences by either calibrating stars in the *R* and *I* bands or adding new comparison stars. Finding charts for 15 of these sequences are also reported.

1. INTRODUCTION

Blazars (i.e., BL Lacertae objects and flat-spectrum radio quasars) constitute a particularly important subclass of active galactic nuclei (AGNs) characterized by high variability at all wavelengths and optical polarization. High-energy emission from many blazars has recently been detected by the EGRET experiment on board the *Compton Gamma Ray Observatory*. Ground-based optical observations, made simultaneously with measurements taken from space by astronomical satellites, such as EGRET, *Rossi X-Ray Timing Explorer*, *Satellite per Astronomia in Raggi X*, *Infrared Space Observatory*, etc., are of utmost importance for understanding the physical mechanisms that cause the complex phenomenology we observe in blazars. Moreover, systematic and continuous optical monitoring of blazars is indispensable for studying the temporal evolution of their variability.

Since 1992, at the Perugia University Observatory, we have had a monitoring program of a sample of relatively bright blazars (Fiorucci & Tosti 1996b; Tosti & Fiorucci 1996). The observations are carried out by an Automatic Imaging Telescope that is able to take measurements, without any human intervention, every time the sky is clear (Tosti, Pascolini, & Fiorucci 1996). One of the principal difficulties encountered during our monitoring was the lack of comparison sequences, suitable for use in CCD differential photometry, for most of blazars included in our sample.

In a previous paper (Fiorucci & Tosti 1996a) we reported *VRI* comparison stars in the field of 12 BL Lac objects. Further, our data were used to calibrate the comparison stars in the fields of PKS 0422+004 (Massaro et al. 1996), S5 0716+714 (Ghisellini et al. 1997), S4 0954+658 (Villata et al. 1998), PKS 0735+178, and S2 0109+224 (Tosti et al. 1998).

In this paper we present a new list of *VRI* magnitudes for comparison stars in the field of the 16 BL Lac objects and active quasars listed in Table 1.

2. OBSERVATIONS

All the observations were taken with the automatic 0.40 m telescope at the Perugia University Observatory. The telescope is equipped with a CCD camera and *BV* (Johnson)–*RI* (Cousins) filters. The monitoring program is mainly carried out only in the *VRI* broad bands because of the reduced sensitivity of the CCD in the *B* band; this filter is therefore used only for the brightest sources.

All the CCD frames were corrected for bias and dark signal. Because of the high grade of uniformity of our CCD chip, the usual flat-field correction of the images was not required (see Tosti et al. 1996). In order to obtain *VRI* secondary standard sequences, the comparison stars were calibrated by observing, on photometric nights, several standard stars (Landolt 1983a, 1983b, 1992). The data were reduced and analyzed following the procedure described by Fiorucci & Tosti (1996a).

Table 1 gives the list of the fields selected. Column (1) reports the blazar designation, columns (2) and (3) report the epoch J2000 coordinates of the objects, column (4) reports the type of the source (i.e., BL Lac object or flat-spectrum radio quasar), column (5) gives the redshift as published, and column (6) gives the name (or names) commonly used in the literature. Half the selected objects either have no *VRI* comparison sequence or have comparison stars that are not calibrated in the *R* and *I* bands. The sources 0235+164, 0323+022, 0754+100, 3C 273, 1308+326, 1415+259, and 1458+228 were already provided with *VRI* comparison sequences. For these fields, we tested the goodness and the stability of the previous calibrations and added new stars to the existing sequences.

3. RESULTS

For each BL Lac object listed in Table 1, comparison stars were chosen from among the closest ones. Figure 1 reports the finding charts extracted from the STScI Digitized Sky Survey (DSS) accessible via World Wide Web.

Table 2 summarizes our photometric calibrations. The names of comparison stars are given in column (1) below the name

TABLE 1
LIST OF BLAZARS SELECTED IN THIS ARTICLE

Source (1)	R. A. (2000) (2)	Decl. (2000) (3)	Type[a] (4)	z (5)	Common Names (6)
0235+164	02 38 38.9	16 36 59	BL Lac	0.940	AO 0235+164
0300+470	03 03 35.2	47 16 16	BL Lac	...	4C 47.08
0316+413	03 19 48.0	41 30 42	BL Lac	0.017	NGC 1275, 3C 84
0323+022	03 26 13.8	02 25 14	BL Lac	0.147	H 0323+022, 1ES 0323+022
0414+009	04 16 52.4	01 05 24	BL Lac	0.287	1H 0414+009
0754+100	07 57 06.6	09 56 35	BL Lac	0.660	PKS 0754+100, OI 090.4
0806+526	08 09 49.2	52 18 58	BL Lac	...	1ES 0806+524
1226+023	12 29 06.6	02 03 08	FSRQ	0.158	3C 273, PKS 1226+023
1308+326	13 10 28.6	32 20 43	BL Lac	0.996	B2 1308+326
1415+259	14 17 56.6	25 43 26	BL Lac	0.237	1E 1415+259
1458+228	15 01 01.9	22 38 06	BL Lac	0.235	1E 1458+2249, MS 14588+224
1611+343	16 13 40.9	34 12 48	FSRQ	1.404	DA 406
1749+096	17 51 32.7	09 39 01	FSRQ	0.322	OT 081
2251+158	22 53 57.7	16 08 53	FSRQ	0.859	3C 454.3, PKS 2251+158
2254+074	22 57 17.2	07 43 12	BL Lac	0.190	PKS 2254+074
2344+514	23 47 04.8	51 42 18	BL Lac	0.044	1ES 2344+514

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

[a] BL Lac = BL Lac object; FSRQ = flat-spectrum radio quasar.

of the blazar to which they are referred. As in Fiorucci & Tosti (1996a), we have used the letter "C" followed by a progressive number to label the comparison stars that, as far as we know, were calibrated for the first time during this work. In the other cases, the designations reported in column (1) are those reported in previously published papers (see col. [8]). Columns (2) and (3) give the J2000 coordinates measured directly on the CCD images. Columns (4), (5), and (6) report the *VRI* magnitudes with their associated errors. Column (7) gives the number of photometric nights used for the calibration. For most of the sequences reported in this paper, we have a substantial number of observations obtained on different photometric nights, but Table 2 reports only the data obtained with the better CCD images and with the higher signal-to-noise ratio. The magnitudes, with their associated standard deviations, are the weighted means of the values obtained with these CCD images.

We also checked the variability of the comparison stars by analyzing the differences in magnitudes during our monitoring program (Fiorucci & Tosti 1996b), and we accepted only the stars with no indication of variability during the entire period of monitoring.

3.1. Notes on Individual Objects

0235+164.—Smith et al. (1985) report the *UBVRI* magnitudes for stars 1, 2, and 3 in the field of 0235+164 ($V = 13.03 \pm 0.03$, $R = 12.69 \pm 0.02$, and $I = 12.35 \pm 0.03$ for star 1; $V = 12.71 \pm 0.02$, $R = 12.23 \pm 0.02$, and $I = 11.79 \pm 0.02$ for star 2; $V = 12.92 \pm 0.02$, $R = 12.48 \pm 0.03$, and $I = 12.08 \pm 0.03$ for star 3). McGimsey, Miller, & Williamon (1976) measured the *UBV* magnitudes for stars 1 ($V = 13.05$), 2 ($V = 12.72$), 3 ($V = 12.92$), 6 ($V = 14.00$), and 7 ($V = 14.98$). We can confirm the stability of these stars since our data are in agreement with the previous measurements. In addition, we have measured the *R* and *I* magnitudes of stars 6 and 7 and have added another comparison star (C1) to the sequence.

0300+470.—As far as we know, no comparison stars have previously been published for this BL Lac object.

0316+413.—For NGC 1275, too, as far as we know, no comparison stars have previously been published, and, therefore, our measurement may be very useful for evaluating source magnitude using differential photometry. This object belongs to the Perseus cluster of galaxies; for this reason, we singled out all the galaxies present in the field of our CCD image and included in our sequence only those objects also having a point source aspect on the DSS images.

0323+022.—Smith, Jannuzi, & Elston (1991) have measured the *UBVRI* magnitudes of star A ($V = 12.84 \pm 0.01$, $R = 12.32 \pm 0.01$, and $I = 11.83 \pm 0.01$) and of star B ($V = 14.40 \pm 0.01$, $R = 14.02 \pm 0.01$, and $I = 13.61 \pm 0.01$) in the field of 0323+022. Our data are in good agreement with these values, and we also include three new comparison stars (C1–C3).

0414+009.—As far as we know, no comparison stars have previously been published for this BL Lac object.

0754+100—Miller, Mullikin, & McGimsey (1983) measured the *UBV* magnitudes of stars A ($V = 14.44$), B ($V = 12.96$), C ($V = 14.71$), and G ($V = 13.21$) in the field of 0754+100. For the same stars we obtained *V* magnitudes that are fainter than those reported by these authors. Considering the typical errors, our calibrations agree with the data reported by Smith et al. (1985): $V = 14.43 \pm 0.07$, $R = 14.13 \pm$

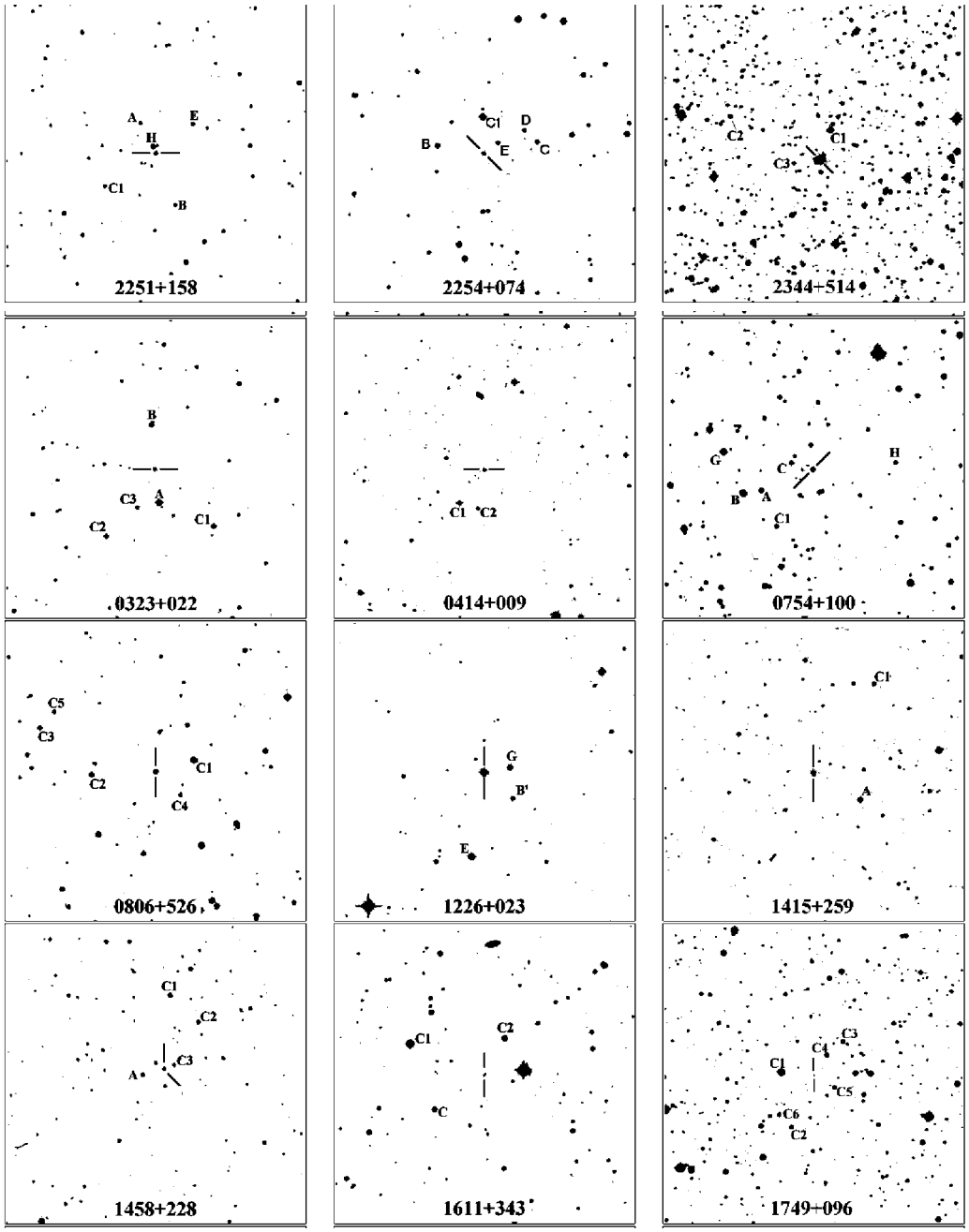

FIG. 1.—Finding charts of the selected blazars. North is at the top, and east is to the left. Each squared box is 10′ wide.

TABLE 2
VRI MAGNITUDES OF THE SELECTED COMPARISON STARS

Name (1)	R.A. (J2000) (2)	Decl. (J2000) (3)	*V* (4)	*R* (5)	*I* (6)	Number (7)	References (8)
0235+164	02 38 38.9	+16 36 59					
1	02 38 36.7	+16 36 28	13.07 ± 0.04	12.73 ± 0.04	12.44 ± 0.08	9	1, 2
2	02 38 32.4	+16 36 01	12.75 ± 0.03	12.27 ± 0.03	11.89 ± 0.08	3	1, 2
3	02 38 29.7	+16 36 44	12.95 ± 0.04	12.48 ± 0.04	12.11 ± 0.08	3	1, 2
6	02 38 45.1	+16 38 47	14.02 ± 0.05	13.64 ± 0.04	13.30 ± 0.07	9	1
7	02 38 39.7	+16 37 21	15.01 ± 0.05	14.32 ± 0.05	13.78 ± 0.08	9	1
C1	02 38 45.6	+16 37 38	14.78 ± 0.05	14.23 ± 0.05	13.76 ± 0.08	9	
0300+470	03 03 35.2	+47 16 16					
C1	03 03 27.0	+47 16 54	12.95 ± 0.03	12.30 ± 0.03	11.76 ± 0.03	5	
C2	03 03 37.8	+47 17 40	13.55 ± 0.04	13.13 ± 0.04	12.73 ± 0.04	8	
C3	03 03 28.7	+47 15 22	13.58 ± 0.04	12.90 ± 0.04	12.28 ± 0.04	7	
C4	03 03 27.1	+47 18 31	14.00 ± 0.04	13.51 ± 0.04	13.03 ± 0.04	5	
C5	03 03 34.5	+47 16 22	14.75 ± 0.05	14.36 ± 0.04	14.01 ± 0.04	8	
C6	03 03 32.6	+47 17 26	14.95 ± 0.06	14.37 ± 0.06	13.78 ± 0.05	8	
C7	03 03 33.8	+47 17 16	15.01 ± 0.05	14.49 ± 0.05	14.01 ± 0.05	8	
C8	03 03 31.6	+47 18 21	15.03 ± 0.05	14.70 ± 0.05	14.35 ± 0.05	8	
C9	03 03 37.8	+47 15 01	15.24 ± 0.06	14.74 ± 0.05	14.34 ± 0.05	5	
0316+413	03 19 48.0	+41 30 42					
C1	03 19 47.9	+41 32 49	12.40 ± 0.03	12.05 ± 0.03	11.69 ± 0.03	11	
C2	03 19 54.9	+41 31 35	12.90 ± 0.03	12.62 ± 0.03	12.36 ± 0.03	11	
C3	03 19 50.2	+41 31 26	13.76 ± 0.04	13.15 ± 0.04	12.54 ± 0.04	13	
C4	03 19 59.0	+41 31 01	14.04 ± 0.04	13.68 ± 0.04	13.33 ± 0.04	7	
C5	03 19 45.2	+41 30 57	14.56 ± 0.04	13.99 ± 0.04	13.46 ± 0.04	12	
C6	03 19 42.1	+41 32 53	14.83 ± 0.04	14.15 ± 0.04	13.39 ± 0.04	7	
0323+022	03 26 13.8	+02 25 14					
A	03 26 13.3	+02 24 07	12.85 ± 0.03	12.33 ± 0.03	11.82 ± 0.03	10	3
B	03 26 14.2	+02 26 43	14.38 ± 0.04	14.01 ± 0.04	13.64 ± 0.04	10	3
C1	03 26 20.6	+02 23 01	14.00 ± 0.04	13.34 ± 0.04	12.81 ± 0.04	7	
C2	03 26 05.9	+02 23 19	14.44 ± 0.04	13.84 ± 0.04	13.32 ± 0.04	7	
C3	03 26 16.2	+02 23 58	15.75 ± 0.05	15.36 ± 0.05	14.93 ± 0.05	7	
0414+009	04 16 52.4	+01 05 24					
C1	04 16 55.8	+01 04 18	13.95 ± 0.05	13.56 ± 0.05	13.15 ± 0.05	10	
C2	04 16 53.3	+01 04 06	15.17 ± 0.07	14.63 ± 0.07	14.06 ± 0.07	10	
0754+100	07 57 06.6	+09 56 35					
A	07 57 13.7	+09 55 55	14.48 ± 0.03	14.15 ± 0.03	13.84 ± 0.04	3	2, 4
B	07 57 16.2	+09 55 50	13.02 ± 0.03	12.66 ± 0.03	12.30 ± 0.04	3	2, 4
C	07 57 09.5	+09 56 49	14.80 ± 0.05	14.33 ± 0.05	13.90 ± 0.04	6	4
G	07 57 18.8	+09 57 13	13.28 ± 0.05	12.88 ± 0.05	12.49 ± 0.05	3	4
H	07 56 55.3	+09 56 46	15.68 ± 0.08	15.25 ± 0.07	14.85 ± 0.06	3	2
C1	07 57 11.7	+09 54 43	15.29 ± 0.06	14.94 ± 0.06	14.58 ± 0.06	3	
0806+526	08 09 49.2	+52 18 58					
C1	08 09 44.2	+52 19 19	13.04 ± 0.05	12.56 ± 0.05	12.14 ± 0.05	3	
C2	08 09 57.5	+52 18 50	14.61 ± 0.05	14.22 ± 0.04	13.86 ± 0.04	3	
C3	08 10 04.6	+52 20 18	14.77 ± 0.05	14.39 ± 0.05	14.04 ± 0.05	3	
C4	08 09 45.8	+52 18 12	15.49 ± 0.06	15.14 ± 0.06	14.81 ± 0.06	3	
C5	08 10 02.7	+52 20 48	15.62 ± 0.06	15.32 ± 0.05	14.99 ± 0.06	3	
1226+023	12 29 06.6	+02 03 08					
E	12 29 08.5	+02 00 20	12.72 ± 0.03	12.31 ± 0.03	11.90 ± 0.03	6	2, 5, 6
G	12 29 03.0	+02 03 17	13.54 ± 0.04	13.19 ± 0.03	12.86 ± 0.04	12	2, 5, 6
B′	12 29 02.7	+02 02 15	14.89 ± 0.05	14.22 ± 0.04	13.60 ± 0.05	12	5
1308+326	13 10 28.6	+32 20 43					
C	13 10 34.0	+32 17 51	13.58 ± 0.03	13.20 ± 0.03	12.84 ± 0.03	5	2, 7
1415+259	14 17 56.6	+25 43 26					
A	14 17 50.1	+25 42 30	14.35 ± 0.04	13.78 ± 0.04	13.29 ± 0.04	15	3
C1	14 17 48.0	+25 46 19	16.39 ± 0.07	15.47 ± 0.07	14.25 ± 0.06	10	

TABLE 2
(*Continued*)

Name (1)	R.A. (J2000) (2)	Decl. (J2000) (3)	*V* (4)	*R* (5)	*I* (6)	Number (7)	References (8)
1458+228	15 01 01.9	+22 38 06					
A	15 01 04.7	+22 37 54	15.58 ± 0.06	15.08 ± 0.05	14.57 ± 0.05	10	3
C1	15 01 01.0	+22 40 33	14.90 ± 0.05	14.55 ± 0.05	14.19 ± 0.05	5	
C2	15 00 57.2	+22 39 39	15.36 ± 0.06	14.93 ± 0.05	14.47 ± 0.06	5	
C3	15 01 00.5	+22 38 14	16.44 ± 0.09	15.90 ± 0.07	14.45 ± 0.09	10	
1611+343	16 13 40.9	+34 12 48					
C	16 13 47.7	+34 11 38	14.13 ± 0.04	13.69 ± 0.04	13.29 ± 0.04	8	6
C1	16 13 50.7	+34 13 48	13.71 ± 0.03	13.34 ± 0.03	13.00 ± 0.03	8	
C2	16 13 38.3	+34 14 01	12.14 ± 0.03	11.63 ± 0.03	11.14 ± 0.03	7	
1749+096	17 51 32.7	+09 39 01					
C1	17 51 37.0	+09 39 09	11.95 ± 0.04	11.45 ± 0.04	11.00 ± 0.03	5	
C2	17 51 35.5	+09 37 18	14.17 ± 0.04	13.75 ± 0.04	13.38 ± 0.04	5	
C3	17 51 28.7	+09 40 10	14.23 ± 0.04	13.80 ± 0.04	13.39 ± 0.04	4	
C4	17 51 31.0	+09 39 43	14.36 ± 0.04	13.94 ± 0.04	13.55 ± 0.04	5	
C5	17 51 29.5	+09 38 35	14.89 ± 0.04	14.45 ± 0.04	14.02 ± 0.04	4	
C6	17 51 37.2	+09 37 40	14.91 ± 0.05	14.32 ± 0.05	13.88 ± 0.04	5	
2251+158	22 53 57.7	+16 08 53					
A	22 53 59.8	+16 09 53	15.86 ± 0.09	15.32 ± 0.09	14.80 ± 0.06	5	5
B	22 53 55.2	+16 07 08	15.21 ± 0.06	14.73 ± 0.05	14.31 ± 0.05	6	5
E	22 53 52.6	+16 09 50	15.76 ± 0.09	14.92 ± 0.08	14.26 ± 0.08	4	5
H	22 53 58.1	+16 09 06	13.65 ± 0.04	13.10 ± 0.04	12.58 ± 0.04	6	5
C1	22 54 04.7	+16 07 47	15.67 ± 0.06	15.27 ± 0.06	14.71 ± 0.06	5	
2254+074	22 57 17.2	+07 43 12					
B	22 57 23.5	+07 43 28	13.97 ± 0.04	13.53 ± 0.04	13.13 ± 0.04	10	5
C	22 57 09.8	+07 43 34	15.04 ± 0.05	14.55 ± 0.05	14.08 ± 0.05	5	2
D	22 57 11.6	+07 43 57	15.10 ± 0.07	14.78 ± 0.06	14.41 ± 0.06	5	2
E	22 57 15.2	+07 43 32	15.30 ± 0.05	14.94 ± 0.05	14.56 ± 0.05	10	5
C1	22 57 17.3	+07 44 24	12.71 ± 0.03	12.21 ± 0.03	11.79 ± 0.03	10	
2344+514	23 47 04.8	+51 42 18					
C1	23 47 03.5	+51 43 19	12.61 ± 0.04	12.25 ± 0.04	11.90 ± 0.04	8	
C2	23 47 16.8	+51 43 44	14.62 ± 0.06	14.20 ± 0.05	13.84 ± 0.04	7	
C3	23 47 07.9	+51 42 10	15.89 ± 0.08	15.40 ± 0.08	14.89 ± 0.08	8	

NOTE.—Units of right ascension are hours, minutes, and seconds, and units of declination are degrees, arcminutes, and arcseconds.

REFERENCES.—(1) McGimsey et al. 1976; (2) Smith et al. 1985; (3) Smith et al. 1991; (4) Miller et al. 1983; (5) Craine 1977; (6) Villata et al. 1997; (7) Miller et al. 1984.

0.06, and $I = 13.83 \pm 0.07$ for star A; $V = 12.98 \pm 0.05$, $R = 12.63 \pm 0.06$, and $I = 12.30 \pm 0.06$ for star B; $V = 15.69 \pm 0.06$, $R = 15.22 \pm 0.09$, and $I = 14.82 \pm 0.10$ for star H. We added another comparison star (C1) to the existing sequence.

0806+526.—For this BL Lac object, as far as we know, no comparison stars have previously been published.

1226+023.—For the E and G comparison stars in the field of the variable quasar 3C 273, Smith et al. (1985) obtained $V = 12.69 \pm 0.04$, $R = 12.27 \pm 0.05$, and $I = 11.84 \pm 0.04$ and $V = 13.56 \pm 0.05$, $R = 13.16 \pm 0.05$, and $I = 12.83 \pm 0.05$, respectively. Villata et al. (1997) report the *B* and *R* magnitudes for star E ($R = 12.28$), and G ($R = 13.17$). There is good agreement between our VRI results and the previous measurements. Moreover, we obtained the VRI magnitudes of star B′ reported by Craine (1977).

1308+326.—Miller et al. (1984, 1985) reported the *UBV* comparison sequences in the field of the BL Lac object 1308+326, while *UBVRI* magnitudes were reported by Smith et al. (1985). The value of the *V* magnitude of star C given by Smith et al. (1985) ($V = 13.70 \pm 0.05$, $R = 13.28 \pm 0.05$, and $I = 12.93 \pm 0.04$) is fainter than that reported by Miller et al. (1985) ($V = 13.60 \pm 0.01$). We obtained new measurements for star C that substantially confirm the photoelectric data of Miller et al. (1985). The finding chart for 1308+326 can be found in the previously cited works and is not reproduced here since we were not able to add new comparison stars for this source.

1415+259.—For the BL Lac object 1415+259, our data are in good agreement with the magnitudes reported by Smith et al. (1991) on star A ($V = 14.34 \pm 0.01$, $R = 13.76 \pm 0.01$, and $I = 13.29 \pm 0.01$). We added another comparison star (C1) so as better to estimate the source magnitude in differential photometry.

1458+228.—For this BL Lac object, too, our data are in good agreement with the magnitudes reported by Smith et al. (1991) on star A ($V = 15.58 \pm 0.01$, $R = 15.06 \pm 0.01$, and $I = 14.60 \pm 0.01$). We added three new comparison stars (C1–C3) to the sequence.

1611+343.—Villata et al. (1997) report the *BVR* magnitudes for star C ($V = 14.15$ and $R = 13.68$) in the field of DA 406. Our data are in agreement with these measurements, and we also added new comparison stars (C1–C2) to the sequence.

1749+096.—The comparison stars in the field of OT 081 have already been reported by Craine (1977) in the *U*, *B*, and *V* broad bands. Only one of these comparison stars is within the field covered by our CCD but it is too faint to be included in our study. We added a new *VRI* sequence more suitable for use in differential photometry in the small field of view usually available with CCD cameras.

2251+158.—In the field of the active quasar 3C 454.3, our calibrations in the *V* broad band are in agreement with the data reported by Craine (1977) for stars A ($V = 15.85$), B ($V = 15.16$), E ($V = 15.88$), and H ($V = 13.65$). We also calibrated these stars in the *R* and *I* bands and we added another comparison star (C1) to the sequence.

2254+074.—In the field of this BL Lac object, our calibrations in the *V* broad band are in agreement with the data reported by Craine (1977) for stars B ($V = 13.96$), C ($V = 15.00$), D ($V = 15.05$), and E ($V = 15.32$). For these stars we obtained the *R* and *I* magnitudes and added a new comparison star (C1) to the sequence.

2344+514.—This X-ray–selected BL Lac object (Perlmann et al. 1996) has recently been detected at TeV energies by the Whipple Observatory and is therefore subject to intensive multiwavelength monitoring. As far as we know, no comparison stars have previously been published for this source.

4. CONCLUSIONS

The study of the variability shown by blazars is one of the most important tools for exploring the physics of the AGN central engine. Nevertheless, for many sources, there is a lack of comparison sequences suitable for use in CCD differential photometry.

In this paper *VRI* comparison stars in the field of 16 blazars have been presented. For 0300+470, 0316+416, 0414+009, 0806+526, and 2344+514, comparison sequences have been given for the first time. We also reported a completely new sequence for 1749+096 and improved the existing sequence of the other objects listed in Table 1.

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