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UBVRI PHOTOELECTRIC PHOTOMETRY IN THE FIELDS OF FIFTEEN ACTIVE GALAXIES

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ABSTRACT

UBVRI photoelectric sequences are presented near fifteen active galactic nuclei (AGNs). A total of 473 observations have been secured for 118 stars, giving an average of 4.0 observations per star and 7.9 stars per sequence.

I. INTRODUCTION

Variability in the continuum and in the emission-line intensities and profiles of active galactic nuclei (AGNs) are very powerful constraints on models for the central engine driving the nuclear activity. Variability in all wavelength domains is well documented for many quasars and Seyfert galaxies. Optical variability was found in the 1960s for quasars and later on for Seyfert nuclei. During the 1970s and 1980s a large body of photometric information has been gathered (see Dibai and Lyutyi 1984; Pica *et al.* 1980, and references therein), but very often it has proved to be difficult to compare data taken by different authors. A photometric disagreement for a given object between datasets does not necessarily mean variability, as people are often willing to conclude. A careful photometric check needs to be done beforehand.

During 1985, we monitored 91 AGNs in the $UBV(RI)_{KC}$ photoelectric system at Cerro Tololo Inter-American Observatory (CTIO). The program contained objects brighter than 15th magnitude, including quasars, Seyfert 1's, Seyfert 2's, and objects with peculiar nuclei from the list of Sérsic and Pastoriza (1965). The photometric data for the AGNs were presented by Hamuy and Maza (1987). During that program, we obtained photoelectric magnitudes for stars around some of the brightest and more interesting objects in our list, in order to have nearby comparison stars for future monitoring programs and also to establish quality photoelectric sequences that could be used by other people in photographic monitoring of these objects. In this paper, we present the sequences obtained during that program.

II. OBSERVATIONS AND RESULTS

All observations were secured using the 0.6, 0.9, and 1 m telescopes at CTIO during several photometric nights from February 1985 through January 1986. We used a single-channel photometer in the photon-counting mode and standard Tololo $UBV(RI)_{KC}$ filters as described by Graham (1982) with a dry-ice-cooled GaAs photomultiplier, either an RCA 31034 or a Hamamatsu. All stars were observed through a 17.0" diaphragm.

Extinction coefficients were derived each night; typical values were $k_v = 0.16$, $k_{u-b} = 0.28$, $k'_{b-v} = 0.13$, $k''_{b-v} = -0.03$, $k_{v-r} = 0.05$, and $k_{r-i} = 0.04$. Transformation coefficients to the standard $UBV(RI)_{KC}$ system were derived each night from observations of at least 20 standard stars. Extinction and standard stars were selected from the list of Graham (1982). Typical transformation equations were the following:

$$(U-B) = 0.988\ (u-b)_0 - 0.488, \quad \sigma = 0.012,$$
$$(B-V) = 0.987\ (b-v)_0 + 0.267, \quad \sigma = 0.011,$$
$$(V-R) = 0.945\ (v-r)_0 - 0.319, \quad \sigma = 0.007,$$
$$(R-I) = 0.978\ (r-i)_0 + 1.123, \quad \sigma = 0.009,$$
$$V = v_0 - 0.045\ (B-V) + 21.197, \quad \sigma = 0.011.$$

We integrated in each passband for at least 4 s up to a maximum of either 90 s or until obtaining a statistical accuracy of 1.5% in U and 1% in the other passbands. The observation of each star was followed by the measurement of the sky contribution.

We observed 118 stars in the surroundings of 15 different active galaxies which are listed in Table I together with their

TABLE I. Fields observed.

Object	Type	α (1950.)	δ (1950.)
TON S 180	S1	00 54 42.0	-22 38 00
FAIRALL 9	S1	01 21 51.2	-59 03 58
NGC 1097	S2	02 44 12.0	-30 29 06
NGC 1672	PN	04 44 55.0	-59 20 12
AKN 120	S1	05 13 38.0	-00 12 15
PKS 0537-441	BL	05 37 09.0	-44 06 40
MCG -5-23-16	S2	09 45 28.4	-30 42 57
NGC 3783	S1	11 36 33.0	-37 27 41
3C 273	QSO	12 26 33.0	+02 19 44
IC 4329A	S1	13 46 27.9	-30 03 41
FAIRALL 51	S1	18 40 15.0	-62 24 58
MKN 509	S1	20 41 26.3	-10 54 18
PKS 2155-304	BL	21 55 58.4	-30 27 54
NGC 7213	S1	22 06 09.0	-47 24 42
NGC 7582	S2	23 15 36.4	-42 38 42

Column 2 code:

S1: Seyfert 1
S2: Seyfert 2
BL: BL Lac
PN: Peculiar Nucleus Galaxy (Sérsic and Pastoriza, 1965)
QSO: Quasar

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coordinates and classification. This yielded an average of 7.9 stars observed in each field. Although our original intention was to observe each star several times, some of them could be observed only twice due to weather constraints. We achieved an average of 4.0 observations per star.

Table II presents the *UBVRI* photometry obtained for all the stars observed. Column 1 gives the star name, columns 2–6 the mean magnitude and colors (errors are given in brackets in units of 0.01 mag), and column 7 the number of observations for that star. Figure 1 [Plates 41–43] presents finding charts for every field where the sequence stars are properly labeled.

The star labeled J in the field of AKN 120 was found to flicker in a timescale of minutes (Hamuy and Maza 1986;

TABLE II. Magnitudes and colors of sequence stars.

(1) Star	(2) V	(3) B-V	(4) U-B	(5) V-R	(6) R-I	(7) n
			TON S 180			
1	9.21(1)	0.39(1)	-0.03(1)	0.24(1)	0.25(1)	4
2	12.74(1)	0.56(1)	-0.01(1)	0.32(1)	0.31(1)	4
3	14.14(1)	0.65(1)	0.06(2)	0.39(1)	0.37(1)	4
4	15.29(2)	1.15(4)	0.66(4)	0.61(1)	0.56(4)	4
5	14.62(1)	0.69(1)	0.12(1)	0.41(1)	0.36(1)	4
6	13.80(1)	0.55(1)	-0.01(1)	0.33(1)	0.33(1)	4
			FAIRALL 9			
1	12.44(1)	0.55(1)	-0.04(1)	0.33(1)	0.34(1)	5
2	13.34(1)	0.76(1)	0.37(1)	0.41(1)	0.39(1)	10
3	15.35(1)	0.60(1)	0.00(1)	0.36(1)	0.38(2)	5
4	14.68(1)	0.71(1)	0.27(1)	0.40(1)	0.32(1)	7
5	14.16(1)	0.65(1)	0.09(1)	0.35(1)	0.35(1)	5
6	13.54(1)	0.82(1)	0.48(1)	0.45(1)	0.39(1)	3
			NGC 1097			
1	11.45(1)	0.65(1)	0.17(1)	0.36(1)	0.35(1)	4
2	11.51(1)	0.73(1)	0.30(1)	0.41(1)	0.36(1)	3
3	13.04(1)	1.23(1)	1.15(1)	0.65(1)	0.61(1)	4
4	13.27(1)	0.64(1)	0.09(1)	0.38(1)	0.36(2)	3
5	13.71(1)	0.68(1)	0.14(1)	0.40(1)	0.39(1)	4
			NGC 1672			
1	9.08(1)	1.29(1)	1.29(1)	0.67(1)	0.61(1)	4
2	12.33(1)	1.01(1)	0.80(1)	0.58(1)	0.51(1)	4
3	9.47(1)	0.86(1)	0.49(1)	0.46(1)	0.43(1)	4
4	11.50(1)	0.97(1)	0.64(1)	0.51(1)	0.50(1)	4
5	12.95(1)	0.60(1)	0.10(1)	0.34(1)	0.34(1)	4
6	13.97(1)	0.65(1)	0.15(2)	0.36(1)	0.40(2)	4
7	12.74(1)	1.25(1)	1.23(2)	0.66(1)	0.60(1)	4
8	13.85(1)	0.63(1)	0.14(2)	0.35(1)	0.31(2)	4
			AKN 120			
A	8.93(1)	1.04(1)	0.83(1)	0.53(1)	0.51(1)	3
B	14.68(1)	0.56(1)	0.01(2)	0.34(1)	0.33(2)	5
C	13.91(1)	0.89(1)	0.54(2)	0.52(1)	0.48(1)	5
D	12.32(1)	0.68(1)	0.12(1)	0.41(1)	0.42(1)	20
E	12.38(1)	1.09(1)	0.86(1)	0.56(1)	0.53(1)	5
F	14.83(1)	0.48(1)	-0.10(4)	0.32(1)	0.31(3)	5
G	11.89(1)	0.65(1)	0.22(1)	0.35(1)	0.35(1)	3
H	11.07(1)	1.04(1)	0.93(1)	0.54(2)	0.47(1)	3
I	13.84(1)	0.69(1)	0.16(2)	0.40(1)	0.39(1)	6
J			Variable			
K	13.92(1)	0.57(1)	0.09(1)	0.33(1)	0.34(1)	18
L	14.95(1)	0.66(1)	0.11(2)	0.38(1)	0.38(3)	4
M	8.46(1)	1.19(1)	1.18(1)	0.60(1)	0.56(1)	3
N	10.38(1)	0.92(1)	0.59(1)	0.52(1)	0.48(1)	3

TABLE II. (continued)

(1) Star	(2) V	(3) B-V	(4) U-B	(5) V-R	(6) R-I	(7) n
			PKS 0537-441			
1	10.68(1)	0.49(1)	0.06(1)	0.28(1)	0.28(1)	4
2	13.20(1)	0.59(1)	0.09(1)	0.33(1)	0.33(1)	4
3	14.08(1)	0.67(1)	0.16(1)	0.37(1)	0.37(1)	4
4	12.79(1)	1.04(1)	0.91(1)	0.54(1)	0.49(1)	4
5	12.81(1)	0.62(1)	0.13(2)	0.32(1)	0.33(1)	4
6	14.48(1)	0.63(1)	0.13(1)	0.34(1)	0.34(1)	4
			MCG-5-23-16			
1	11.58(1)	0.57(1)	0.03(1)	0.34(1)	0.33(1)	4
2	12.14(1)	0.55(1)	-0.01(1)	0.34(1)	0.34(1)	4
3	12.32(1)	0.66(1)	0.09(1)	0.37(1)	0.36(1)	4
4	13.43(1)	0.62(1)	0.11(2)	0.34(1)	0.32(1)	4
5	12.65(1)	1.20(1)	1.16(1)	0.62(1)	0.55(1)	4
6	13.87(1)	0.82(1)	0.44(2)	0.46(1)	0.42(1)	4
7	14.97(1)	0.61(1)	0.03(1)	0.35(1)		4
			NGC 3783			
1	9.19(1)	0.07(1)	0.05(1)	0.04(1)	0.06(1)	3
2	9.85(2)	0.73(1)	0.27(1)	0.41(1)	0.38(1)	4
3	11.03(1)	0.59(1)	0.11(1)	0.34(1)	0.34(1)	3
4	11.99(1)	0.51(1)	-0.01(1)	0.31(1)	0.33(1)	3
5	13.48(1)	0.80(1)	0.40(1)	0.46(1)	0.41(1)	3
6	13.72(2)	0.49(2)	0.04(1)	0.31(1)	0.31(1)	6
7	14.23(1)	0.93(1)	0.55(1)	0.53(1)	0.49(1)	5
8	14.90(1)	0.66(1)	0.04(1)	0.38(1)	0.43(2)	4
9	15.42(1)	0.98(1)		0.57(1)	0.49(2)	4
10	12.84(1)	0.67(1)	0.16(1)	0.39(1)	0.37(1)	3
11	13.31(1)	0.72(1)	0.25(1)	0.42(1)	0.37(1)	4
12	14.98(1)	1.03(1)	0.72(3)	0.58(2)	0.59(3)	5
			3C 273			
B	12.25(1)	0.44(1)	-0.05(1)	0.25(1)	0.28(1)	3
B'	14.92(1)	1.11(1)	0.95(2)	0.70(2)		4
C	11.88(1)	0.99(1)	0.55(1)	0.57(1)	0.56(1)	3
D	12.64(1)	0.55(1)	-0.05(1)	0.31(1)	0.32(1)	3
E	12.71(1)	0.66(1)	0.08(1)	0.39(1)	0.40(1)	3
F	12.93(1)	1.10(1)	0.75(1)	0.59(1)	0.58(1)	5
G	13.53(1)	0.59(1)	0.10(1)	0.34(1)	0.32(1)	3
H	14.08(1)	1.27(1)	1.19(3)	0.80(2)	0.70(1)	5
I	13.84(1)	1.41(1)	1.13(2)	0.92(1)	0.97(1)	5
J	9.23(1)	0.98(1)	0.69(1)	0.51(1)	0.49(1)	3
K	10.45(1)	1.48(1)	1.77(1)	0.82(1)	0.80(1)	4
			IC 4329a			
1	10.34(1)	0.73(1)	0.26(1)	0.41(1)	0.39(1)	3
2	11.10(3)	1.58(1)	1.83(1)	1.03(1)	1.30(1)	5
3	13.00(1)	0.65(1)	0.14(1)	0.36(1)	0.36(1)	3
4	13.44(1)	0.61(1)	0.11(1)	0.36(1)	0.35(1)	5
5	14.07(1)	0.57(1)	-0.04(1)	0.35(1)	0.35(1)	3
6	14.57(1)	0.63(1)	-0.01(5)	0.39(1)	0.37(2)	5
7	14.62(1)	0.81(1)	0.51(3)	0.42(1)	0.40(1)	4
8	11.71(1)	1.27(1)	1.24(1)	0.70(1)	0.65(1)	3
9	13.91(1)	0.57(1)	-0.02(1)	0.32(1)	0.34(1)	3
10	12.63(1)	1.00(1)	0.67(1)	0.52(1)	0.50(1)	4
11	14.84(2)	0.77(2)	0.30(1)	0.41(1)	0.41(1)	6

TABLE II. (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Star	V	B-V	U-B	V-R	R-I	n
			FAIRALL 51			
1	12.83(1)	0.80(1)	0.34(1)	0.44(1)	0.42(2)	3
2	13.37(1)	1.07(1)	0.80(3)	0.59(1)	0.56(1)	3
3	13.51(1)	0.71(1)	0.16(1)	0.42(1)	0.42(1)	3
4	14.10(1)	0.75(2)	0.15(1)	0.42(1)	0.42(1)	4
5	14.36(1)	0.70(1)	0.20(2)	0.42(1)	0.41(3)	3
6	15.61(1)	0.84(1)		0.44(5)		2
7	14.38(1)	0.76(1)	0.19(1)	0.44(1)	0.40(3)	2
8	9.05(1)	0.37(1)	0.00(1)	0.22(1)	0.23(1)	3
			MKN 509			
A	14.54(1)	0.67(1)	0.17(1)	0.35(1)	0.36(1)	3
B	13.12(1)	0.55(1)	0.00(1)	0.32(1)	0.31(1)	4
C	14.02(1)	0.98(1)	0.61(3)	0.60(1)	0.55(1)	4
D	12.41(1)	0.57(1)	0.09(1)	0.32(1)	0.31(1)	5
E	11.38(1)	0.92(1)	0.60(1)	0.51(1)	0.48(1)	4
G	12.55(1)	0.58(1)	-0.05(1)	0.36(1)	0.38(1)	4
H	13.30(1)	0.54(1)	-0.04(1)	0.31(1)	0.33(1)	4
I	14.43(1)	0.59(1)	-0.03(2)	0.37(1)	0.37(1)	2
			PKS 2155-304			
1	9.17(1)	0.40(1)	-0.02(1)	0.23(1)	0.24(1)	3
2	12.05(1)	0.69(1)	0.15(1)	0.38(1)	0.37(1)	4
3	13.00(1)	0.90(1)	0.58(1)	0.53(1)	0.45(1)	4
4	14.28(1)	0.65(1)	0.15(1)	0.36(1)	0.36(1)	3
5	15.35(3)	0.66(1)	-0.01(2)	0.34(1)	0.32(2)	4
			NGC 7213			
1	10.99(1)	0.57(1)	0.09(1)	0.33(1)	0.32(1)	2
2	10.80(1)	0.46(1)	0.03(1)	0.27(1)	0.27(1)	2
3	12.52(1)	1.09(1)	1.02(2)	0.65(1)	0.52(1)	2
4	12.78(1)	0.68(1)	0.18(2)	0.37(1)	0.35(1)	2
5	14.09(1)	0.63(2)	0.16(1)	0.36(3)	0.35(1)	2
			NGC 7582			
1	13.39(1)	0.67(1)	0.12(1)	0.37(1)	0.35(1)	3
2	13.54(1)	0.58(1)	0.05(1)	0.35(1)	0.33(1)	3
3	14.05(1)	0.66(1)	0.12(1)	0.33(1)	0.32(1)	3
4	14.93	0.62	-0.01	0.36	0.34	1
5	12.61(1)	0.66(1)	0.02(2)	0.44(1)	0.44(1)	3
6	12.56(1)	0.60(1)	0.05(1)	0.34(1)	0.32(1)	3

Bond *et al.* 1987) and must obviously be discarded as a comparison star.

Penston *et al.* (1971), Burkhead *et al.* (1968), and Smith *et al.* (1965) observed stars in the *UBV* system in common with us in the field of 3C 273. Miller (1981, 1986) obtained *UBV* photometry for some of the stars that we observed in the fields of AKN 120 and MKN 509. Figure 2 presents the comparison between our values and the previously mentioned photometry, in the sense of (CTIO − others) vs V_{CTIO}. No dependence of the differences on magnitude can be seen. Table III summarizes the mean differences found between the CTIO values and the five datasets previously published, together with the standard deviation of the mean for each case. In general, our values agree well with the previous observations, except for the V magnitudes of Smith *et al.* (1965) in the field of 3C 273. From Table III it can be seen that our $(U-B)$ values appear to be slightly bluer than the rest. The same difference was found by Graham (1982)

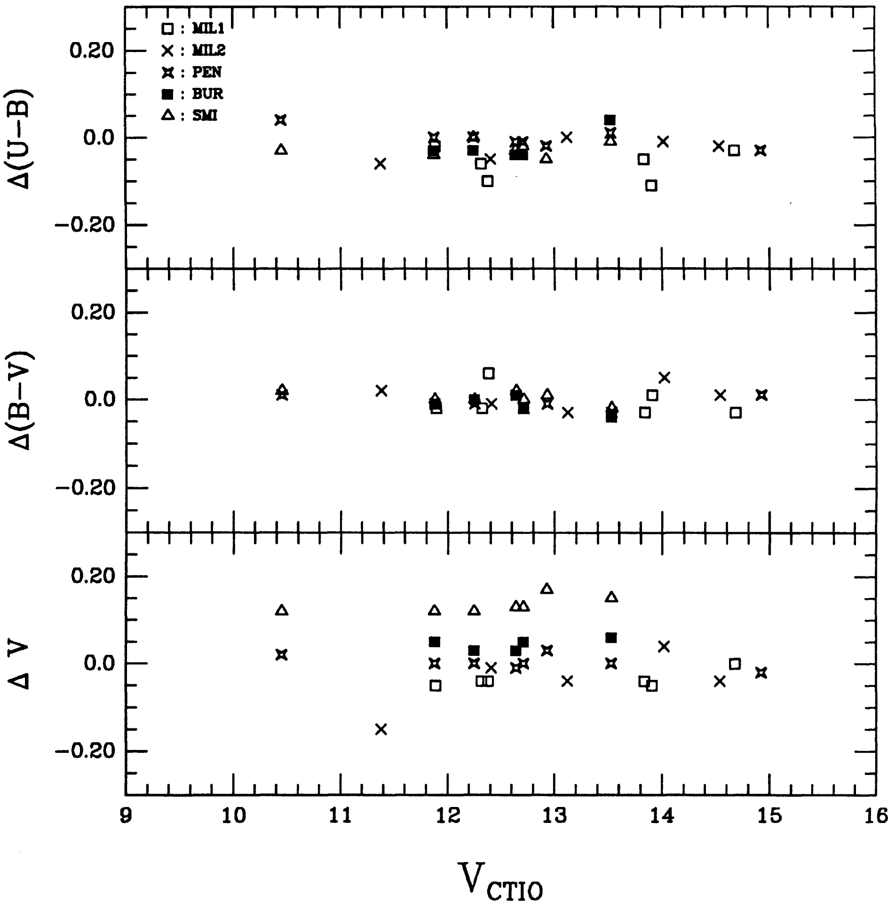

FIG. 2. Comparison of the CTIO *UBV* data with Miller's (1981) data in the field of AKN 120 (MIL1), Miller's (1986) values in the field of MKN 509 (MIL2), Penston *et al.*'s (1971, PEN), Burkhead *et al.*'s (1968, BUR) and Smith's (1965, SMI) data for stars around 3C 273. Different symbols were used to identify the different sets of photometry. The left ordinate refers to differences in colors and magnitudes in the sense of CTIO − others.

TABLE III. Mean differences between CTIO *UBV* values and other observers.

Comparison	ΔV	Δ(B-V)	Δ(U-B)
CTIO-MIL1	-0.039 ± 0.016	+0.007 ± 0.042	-0.071 ± 0.039
CTIO-MIL2	-0.024 ± 0.064	+0.008 ± 0.027	-0.028 ± 0.023
CTIO-PEN	+0.003 ± 0.015	-0.006 ± 0.014	-0.003 ± 0.020
CTIO-BUR	+0.044 ± 0.012	-0.012 ± 0.017	-0.020 ± 0.030
CTIO-SMI	+0.134 ± 0.018	+0.004 ± 0.013	-0.026 ± 0.016

Note for column 1:

MIL1: Miller's (1981) data in the field of AKN 120
MIL2: Miller's (1986) data in the field of MKN 509
PEN : Penston's et al. (1971) data in the field of 3C 273
BUR : Burkhead's et al. (1968) data in the field of 3C 273
SMI : Smith's (1965) data in the field of 3C 273.

when comparing his $(U-B)$ colors with the Cape values (Cousins 1973, 1976), which might be accounted for by slight differences in the photometric systems.

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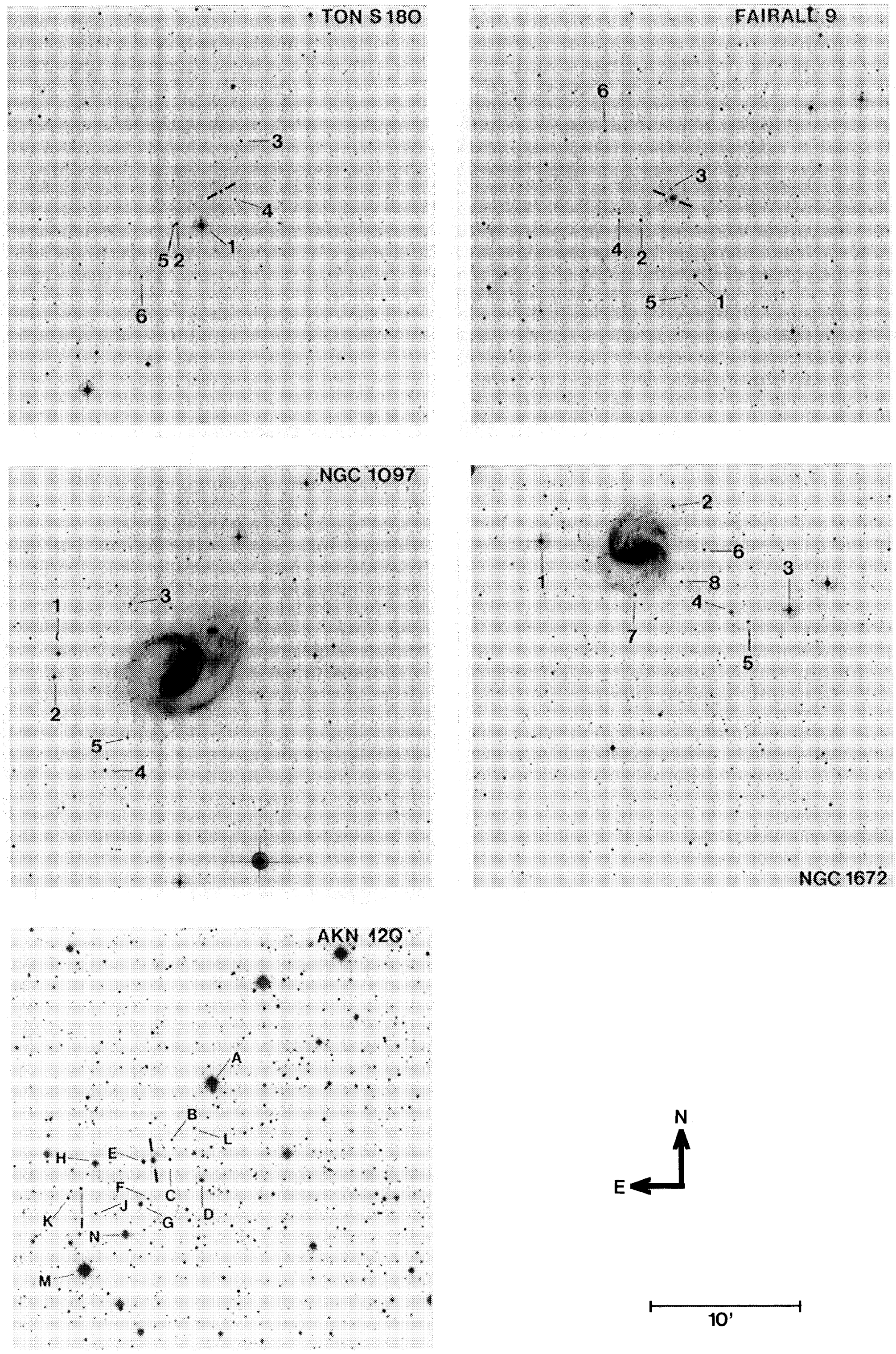

FIG. 1. Finding charts for the comparison sequences in the fields of the 15 active galaxies listed in Table I.

Hamuy and Maza (see page 721)

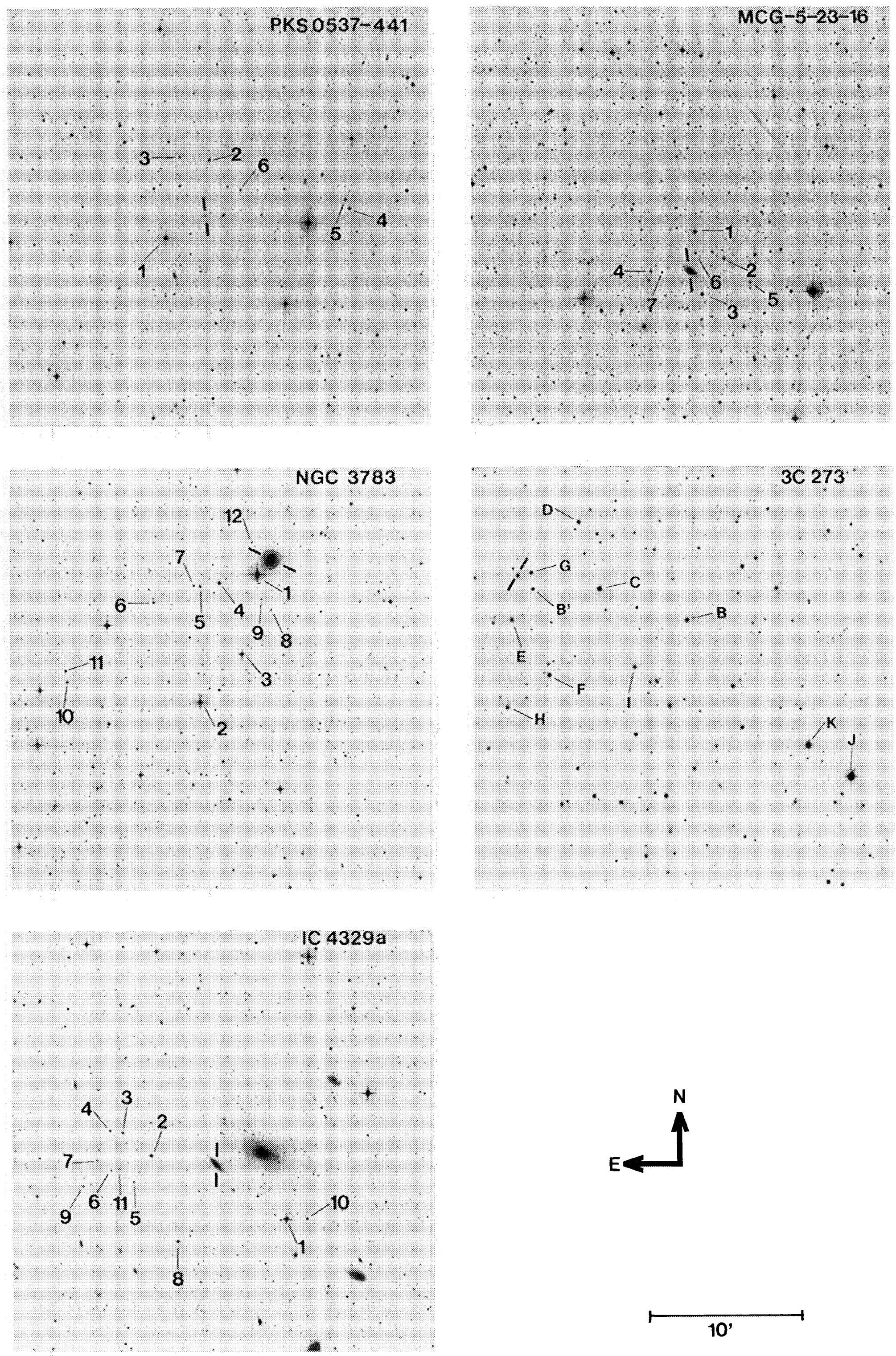

FIG. 1. (continued)

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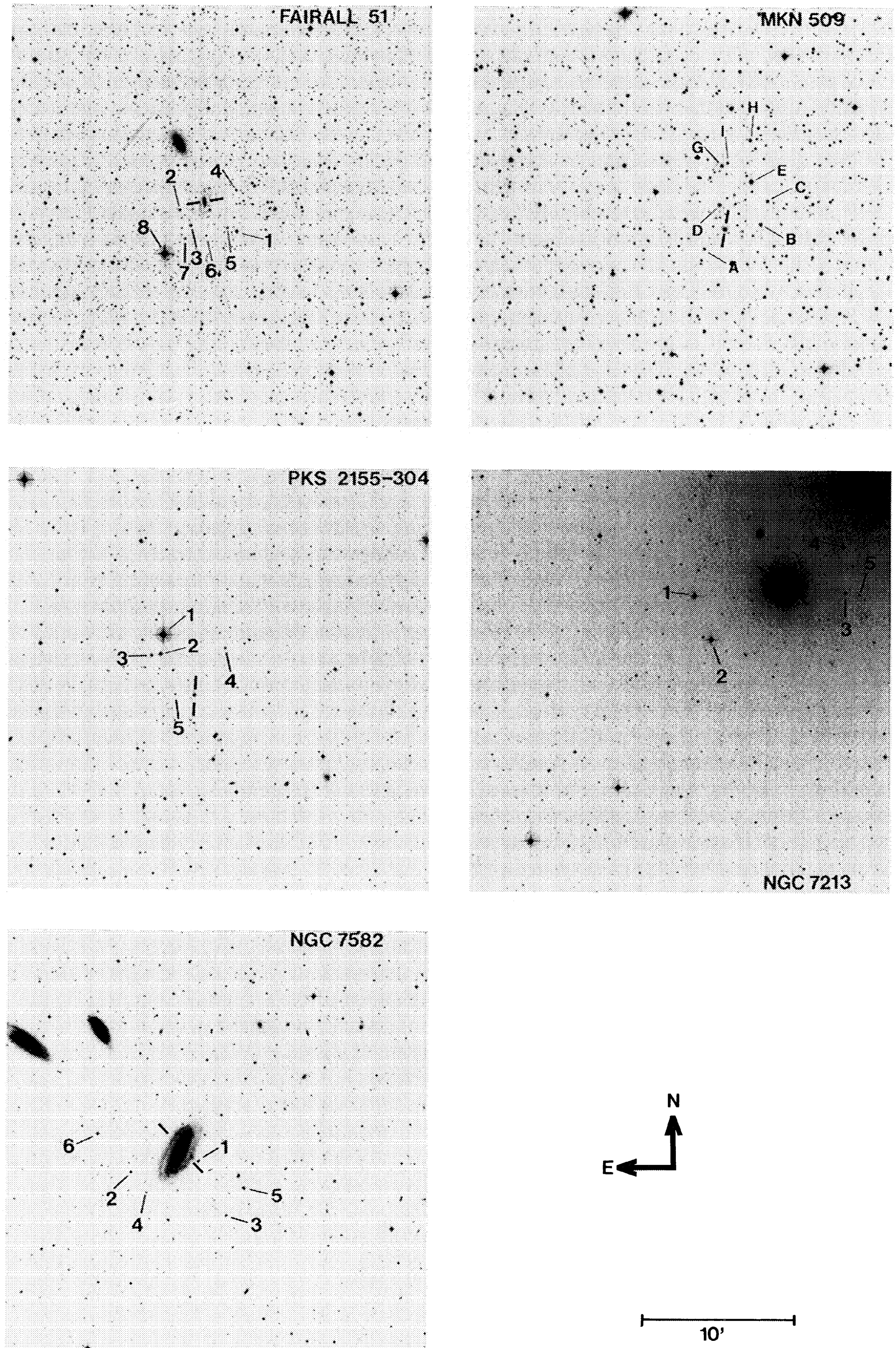

FIG. 1. (continued)

Hamuy and Maza (see page 721)