THE ASTROPHYSICAL JOURNAL, Vol. 151, March 1968

THE STELLAR CONTENT AND DISTANCE OF THE GALAXY NGC 2403 IN THE M81 GROUP

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Received August 9, 1967

ABSTRACT

Fifty-nine variables have been found in the nearby Sc galaxy NGC 2403, which is a member of the M81 group. Of these, seventeen are Cepheids ranging in period from $87^{d}48$ to $20^{d}230$; eight are very bright irregular blue variables of the type previously found in M31 and M33; seventeen are bright, red irregular supergiant variables similar to those in h and χ Per; there is one eclipsing binary; and sixteen are unclassified variables of undetermined nature. NGC 2403 is the first galaxy outside the Local Group in which Cepheids have been detected.

Light-curves have been determined relative to a photoelectric sequence of seventy-three stars which covers the interval from $B = 9.15$ to $B = 22.70$, $V = 8.39$ to $V = 21.80$. Three-color photoelectric observations of the sequence stars brighter than $V = 19.5$ show that the local reddening due to the galactic system is $E(B - V) = 0.06$ mag. The period-luminosity relations for Cepheids in B and V at maximum light provide two well-determined upper envelope fits to the standard P-L function, giving apparent distance moduli of NGC 2403 of $(m - M)_{AB} = 27.80 \pm 0.1$ and $(m - M)_{AV} = 27.75 \pm 0.1$. These reduce to true moduli of $(m - M)_{0,B} = 27.56$, and $(m - M)_{0,V} = 27.57$ from the Cepheids alone.

Four other distance indicators give closely comparable values. (1) Star counts across the face of NGC 2403, corrected for foreground contamination, give $B = 18.25$ for the brightest resolved stars. Previous calibration of $M_B = -9.3$ in galaxies of the Local Group gives $(m - M)_{AB} = 27.55$. (2) The brightest blue irregular variable occurs at $B(\max) = 18.2$, giving $(m - M)_{AB} = 27.5 \pm 0.2$ if $M_B(\max) = -9.3$ is adopted from M31 and M33. (3) The brightest irregular red variable occurs at $V(\max) = 19.98$, $B(\max) = 22.02$. Calibration via the LMC, NGC 6822, and the SMC gives a preliminary value of $M_V(\max) = -8.00$, $M_B(\max) = -6.00$ for these stars, giving apparent moduli of $(m - M)_{AB} = 28.02$, and $(m - M)_{AV} = 27.98$. (4) The angular sizes of the largest, and mean of the first five largest H II regions, calibrated via the LMC and M33, give $(m - M)_{0,L} = 27.54 \pm 0.18$ and $(m - M)_{0,5} = 27.52 \pm 0.40$. The average of all methods is given in Table 12 as $(m - M)_0 = 27.55 \pm 0.13$ (AD). The agreement between the methods is good and provides evidence that no systematic difference exists from galaxy to galaxy among the various distance indicators.

One unexpected result is that the red supergiants, both constant and variable, may be a new and precise distance indicator. There appears to be an upper envelope to the absolute luminosity of these stars at about $M_V = -8.0$. Such red stars can be located with ease in all Sc and Irr galaxies with $(m - M)_{AV} < 29$ by comparing red and blue plates and, therefore, they can be important in an intermediate step for the redetermination of the Hubble constant.

The ratio of mean redshift of the M81 group—each galaxy corrected individually for solar motion—to the distance to NGC 2403 of $r = (3.25 \pm 0.20) \times 10^6$ pc is $v/r = (65 \pm 15)$ km sec^{-1} Mpc^{-1}. This is not claimed to have any relation to the Hubble constant because the sample contains only one group, but similar analysis of many additional groups may eventually lead to an adequate value of H.

I. INTRODUCTION

NGC 2403 ($\alpha_{1950} = 7^{h}32^{m}.0$, $\delta = +65°43'$; $l^{II} = 151°$, $b^{II} = +29°$) is a bright, relatively nearby galaxy beyond the Local Group which closely resembles M33 in stellar content and spiral structure. It has a small or possibly nonexistent nucleus, broad and ill-defined spiral arms, and pronounced resolution into stars beginning at $B \simeq 18.3$ mag. Both galaxies are late Sc systems in the Hubble classification, Sc^{+} in Holmberg's system (1958), Sc III by van den Bergh (1960), and aS4 according to Morgan's system (1958). The galaxy is illustrated in *The Hubble Atlas of Galaxies* (Sandage 1961).

The galaxy forms the western terminus of the group whose central and most prom-

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inent member is M81 (Holmberg 1950), and which includes NGC 2366, M82, NGC 3077, NGC 2976, IC 2574, NGC 4236, Ho I, Ho II, and at least six faint red dwarf elliptical galaxies of the Sculptor and Fornax type (Bowen 1954). This group, together with the M101 group (Holmberg 1950), is of major importance in the systematic redetermination of the Hubble constant, because the galaxies in both are near enough that their stellar contents are highly resolved. Bright stars, H II regions, normal novae, and several types of variable stars can be identified with certainty on plates taken with large reflectors. To determine the Hubble constant these indicators must be calibrated in the nearby groups and then must be located and measured in more distant galaxies where the cosmological redshift becomes significantly larger than the random motions. The M81 and M101 groups do, for the first time, yield to major resolution with the 200-inch reflector, a circumstance which increases substantially the number of galaxies available for the calibration study.

When the Hale telescope went into routine operation in 1949, Hubble, with the help of other members of the nebular department, began a systematic search for variable stars in NGC 2403, M81, M101, and NGC 5194. The first Cepheids outside the Local Group were found in the initial phases of the study, and by 1953 Hubble had isolated twenty-seven variables of various types in NGC 2403, of which seven were definitely Cepheids for which preliminary periods could be assigned.

The problem was continued after Hubble's death, and a report of progress on NGC 2403 and M81 was published in 1954 (Sandage 1954). More plates were obtained until the close of the observing season in 1963, and the present paper is a discussion of the material now available. This is the first of a projected series of reports on the redetermination of the Hubble constant. Future papers will deal with the variables in M81, the variables and resolved stars in M101, the calibration of the linear size of the largest H II regions in Sc and Irr galaxies, and the application of these distance indicators to galaxies out to redshifts of about 2000 km/sec where the angular size of the largest H II region region is expected to be close to 2″.

II. THE PHOTOGRAPHIC MATERIAL

A total of one hundred sixty blue and twenty-two yellow plates are available, covering a time interval from 1910 to 1963. The early plates from 1910 to 1938, twenty-nine in number, were taken with the 60-inch reflector on Mount Wilson by Ritchey, Pease, Duncan, Smith, Hubble, and Baade. No 100-inch plates are available because the galaxy is too far north to be reached by this telescope, due to its particular yoke-type mounting.

The 200-inch material consists of 115 blue plates, taken with Eastman 103aO emulsion, and sixteen photovisual plates taken with Eastman 103aD emulsion. After 1951, most of the blue plates were taken behind either a Schott GG1, a Schott WG2, or a Schott GG13 filter of 2 mm thickness to eliminate the spectral region shortward of $\lambda \simeq$ 3800 Å. No filter was used before that date. The photovisual plates were taken behind a Schott GG11 filter, or occasionally behind a Schott GG14, again of 2 mm thickness, a system which defines a band pass from $\lambda \simeq 5100$ Å to $\lambda \simeq 6300$ Å.

No color equation has been applied to magnitudes determined from the blue plates taken with or without filters. The effect is negligible in all cases where the colors of the sequence stars are similar to the color of the relevant variable star, and the correction for other variables is so much smaller than other errors that it has been neglected. However, the secondary sequence stars are strictly on the B, V system because all transfers from the primary photoelectric sequence were made on plates taken with the standard filters of this system.

Plate information such as name, date, exposure time, and quality is listed in the relevant tables given in the Appendix. The notation, standard at the Observatories until recently, gives the telescope designation as suffix, the running personal number of each observer, and the last name initial of the observer. The telescope designation is S for

60-inch and PH for Palomar-Hale (the 200-inch). The observer's initials are Ri(Ritchey), P(Pease), SS(Sinclair Smith), D(Duncan), H(Hubble), MH(Humason), M(Minkowski), B(Baade), Bm(Baum), A(Arp), and S(Sandage). Thus, plate S-454-H is the 454th plate taken by Hubble at the 60-inch.

III. THE MAGNITUDE SEQUENCES

a) *Photoelectric Data*

A primary photoelectric sequence of seventy-three stars was determined with the 60- and 200-inch telescopes during the 1958–1964 observing seasons. The photometry brighter than $V = 19.5$ presented no particular difficulties because stars could be visually centered in the measuring diaphragm at the prime focus of the 200-inch telescope. Positions for sky readings were determined by inspection of the best plates with limiting magnitude fainter than $B = 23.5$ mag, $V = 22.5$ mag. The mean photometric error for stars brighter than $V = 19.5$ is about ± 0.02 mag in all three colors.

Measurement of stars fainter than $V = 19.5$ required blind offset procedures. Stars for the sequence were chosen from photographic plates so as to be relatively free of background. The X and Y offsets of the faint stars relative to selected bright stars were measured on the plates and were used at the telescope after adjustment insured that the orientation of the photometer base corresponded with the orientation of the plate previously measured in the laboratory.

Uncertainties of the final magnitude values for stars fainter than about $V = 21.5$ arise because there is no assurance that the regions chosen for the sky readings are free from contaminating stars fainter than the plate limit. The influence of such stars on the photoelectric values can be considerable. For example, a star of $B = 21.4$ mag would be measured 0.5 mag too faint if the comparison sky region is contaminated with four stars of $B = 24.0$ mag, or 0.5 mag too bright, if the contaminating stars are in the object hole.

Errors of this size are expected in the NGC 2403 field according to the following calculation. A circular measuring aperture of $6''.7$ diameter was usually used for the faintest stars, and this corresponds to a column through NGC 2403 of 8.8×10^3 pc^2 cross-sectional area, or a volume of 2.6×10^6 pc^3 for a thickness of the disk of 300 pc, assuming a true modulus of $m - M = 27.56$ as derived later. The sequence stars are located in the outer regions of NGC 2403 where the surface brightness is comparable to that of the solar neighborhood in the galactic system. Taking McCuskey's (1966) luminosity function for the solar neighborhood at $M_B = -3.8$ (corresponding to an observed $B = 24.0$ in NGC 2403 at its apparent blue modulus of $[m - M|_{AB} = 27.8)$, gives 10^{-6} stars per pc^3 within the 1-mag interval centered at $M_B = -3.8$. From this, one would expect an average of 2.6 stars of $B = 24.0 \pm 0.5$ mag within the diaphragm. This value will vary from star to star depending on the actual background.

Because the effect is statistical and occurs with both signs, the average of many sequence stars should closely define a true Pogson scale. For this reason, we have smoothed the photoelectric sequence by eye estimates using a step-scale plate selected from a library of such plates made with the 200-inch in different seeing conditions. The smoothing was done for all photoelectric stars fainter than $B = 18.24$ on seven blue and four yellow plates, each measured three times. The mean of the smoothed values is adopted as the primary magnitude sequence as listed in Table 1. The stars are identified in Figure 1 (Plate 2). The magnitude differences between the adopted values and the direct photoelectric values are shown in Figure 2. The agreement is excellent over the entire range.

A check on both the scale and the zero point of this primary sequence was made by measurement of four photographic transfers from SA 51 to NGC 2403 made on nights of excellent seeing. The photoelectric sequence in SA 51 (Baum, unpublished) extends to $B = 22.35$. Three of the four transfers gave concordant results, while the fourth

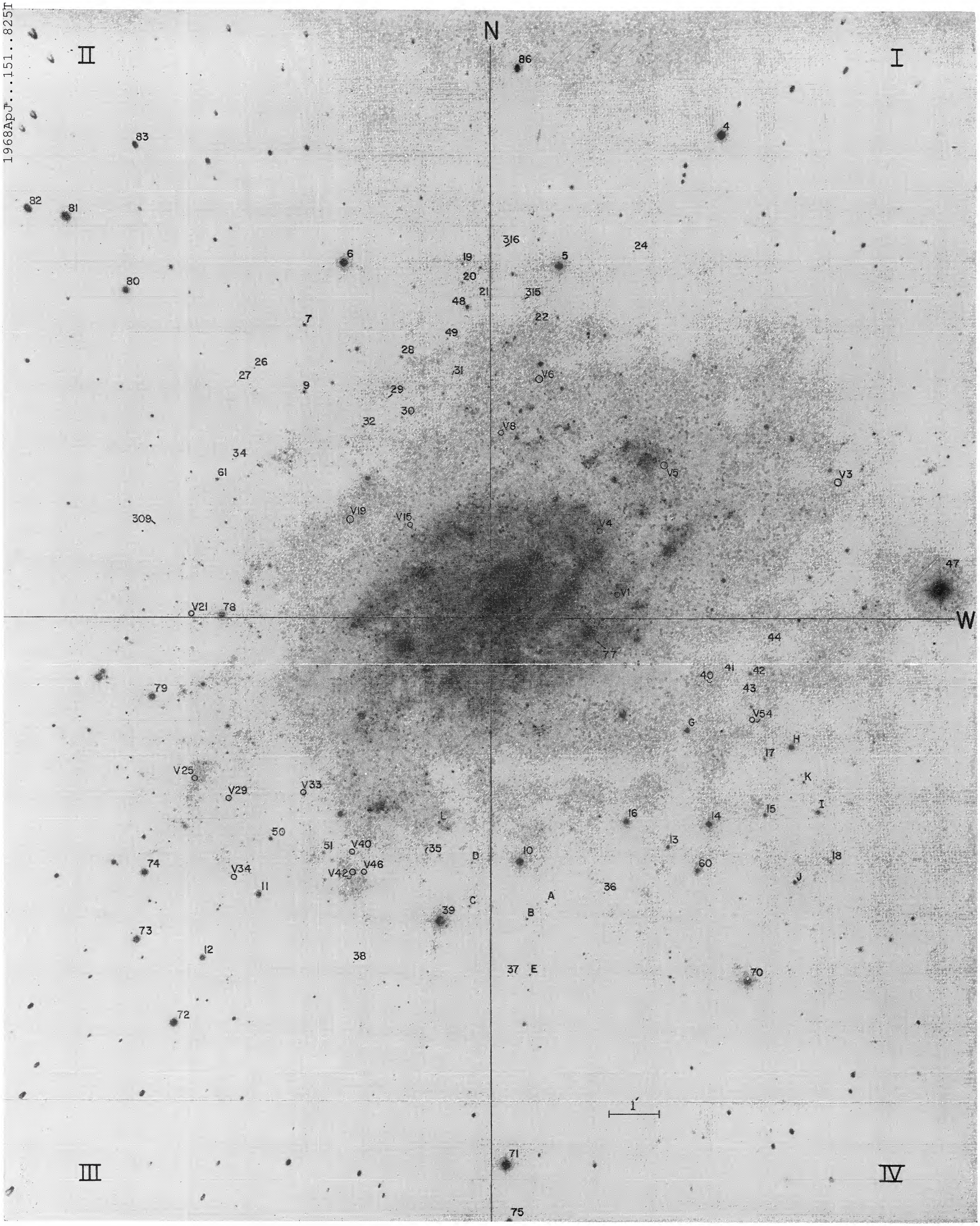

Fig. 1.—Identification chart for the photoelectric standards of Table 1, reproduced from a 200-inch plate of 30-min exposure on Eastman 103aO emulsion behind a Schott GG1 filter. The 17 Cepheids are also identified with their variable star numbers of Table 5.

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TABLE 1

PHOTOELECTRIC STANDARDS AND THE ADOPTED SEQUENCE

No.	Photoelectric B	Photoelectric V	Photoelectric U	No.	Photoelectric B	Photoelectric V	Photoelectric U	Adopted B	Adopted V
BD+65°394.	9 15	8 39	9 50	9	17 72	16 85	18 21	. . .	. ...
47	10 36	9 35	11 14	28	18 16	17 21	18 77	.	.
77	11 32	10 57	11 66	19	18 24	17 40	18 48	18 26±0 03	17 38±0 04
71	12 58	12 01	12 57	K	18 25	17 65	18 29	18 24±0 03	17 65±0 03
39	12 68	11 86	13 05	17	18 37	17 91	18 24	18 40±0 02	17 95±0 04
4	12 81	12 14	12 96	B	19 12	18 82	19 24	19 04±0 04	18 67±0 07
70	13 26	12 91	13 34	32	19 25	18 36	.	19 23±0 01	18 47±0 02
81	13 30	12 57	13 60	C	19 51±0 03	18 31±0 01	20 65±0 12	19 49±0 01	18 39±0 04
6	13 31	12 77	13 23	20	19 73±0 02	18 80±0 04	20 39±0 08	19 78±0 03	18 82±0 04
5	13 379	12 858	13 311	22	19.79±0 01	18 97±0 03	20 11±0 11	19 78±0 02	19 04±0 05
10	13 473	12 862	13 404	D	19 85±0 01	18 51±0 03	20 73±0 11	19 88±0 02	18 43±0 07
72	13 54	13 05	13 50	A	19 86±0 01	18 40±0 03	. .	19 86±0 03	18 33±0 05
73	14 06	13 30	14 28	30	19 90±0 03	(19 52±0 06)	20 09±0 11	19 88±0 03	19 97±0 02
14	14 069	13 146	14 651	E	20 08±0 04	18 71±0 01	21 24±0 08	20 09±0 03	18 74±0 05
75	14 21	13.65	14 20	43	20 37±0 01	20 55±0 09	20 43±0 06	20 43±0 01	20 60±0 03
74	14 29	13.37	14 95	36	20 58±0 01	19 15±0 01	. . .	20 61±0 07	19 10±0 02
78	14 34	13 52	14 71	34	20 65±0 02	19 65±0 03	.	20 68±0 01	19 59±0 03
80	14 43	13 47	15 14	44	20 82±0 04	19 89±0 03		20 81±0 02	19 80±0 04
79	14 46	13 78	14.60	38	20 84±0 02	20 86±0 06	21 10±0 10	20 85±0 05	20 95±0 04
16	14 597	14 068	14 536	24	20 88±0 02	19 30±0 04	..	20 82±0 04	19 18±0 07
82	14 62	14.07	14 63	26.	21 11±0 02	21 05±0 08	.. ..	20 89±0 05	21 06±0 04
H	14 64	13 94	14 83	49	21 09±0 05	19 75±0 04	... .	20 87±0 06	19.71±0 03
86	14 66	14 16	14 59		21 19±0 05*	19 71±0 04*	. .		
12	14 82	14 21	14 80	21	21 18±0 05	19 84±0 03	.. . ..	21 19±0 04	19 88±0 02
G	14 91	14 33	14 91	41	21 22±0 07	19.59±0 04	. .. .	21 33±0 10	19 67±0 03
11	14 96	14 46	14 87	37.	21 27±0 04	21 29±0 11	.	21 20±0.07	21 17±0 08
60	15 31	14.67	15 43	35	(21 88±0 11)	(21 22±0 14)	. .	21 40±0 05	20 85±0 04
83	15 430	14 825	15 49		(22 80±0 15)	(21 40±0 18)	.		
I	15 83	15 18	15 91		(22 15±0.10)*	(21 19±0 16)*	. . .		
48	16 20	15 65	16 14	27	21 55±0 06	21 33±0 05	21 05±0 05	21 53±0 05	21 31±0 03
13	16 311	15 771	16 229	315	21 74±0 10	20 22±0 08	.	21 86±0 07	20 16±0 02
J	16 32	15 40	16 98	31	(21 59±0 04)	20 20±0 06	. . .	21 98±0 02	20 18±0 04
42	16 52	15 66	17 00		21 81±0 10*	(20 49±0 09)*	.		
50	16 62	16 02	16.62	309	22 22±0 17	. .. ..	....	22 04±0.05	21.62±0.02
15	16.65	15 98	16 70	316	(21 91±0 16)	21.60±0 19	. ...	22 54±0 04	21.75
61	17 41	16 76	17 45		22 65±0.15*	. ....	... .		
L	17 43	16 85	17 44	29	22 66±0 04	(22 52±0 15	.	22 67	21 67
7	17 47	16 49	. .		(23 22±0 23)*	(22 38±0 30)*	..		
18	17 55	16 50		40	22 76±0 10	21 79±0 15	.. ..	22 70	21 80
51	17 71	16 90	18 13						

*Data obtained by pulse-counting techniques; all other values are from D C methods using a strip-chart recorder differed in zero point from the other three by 0.25 mag and was discarded. The magnitude of sixty secondary standards, listed among others in Table 2 as discussed in § III*b* were determined in NGC 2403 by step-scale estimates of the transfer plates measured in the order SA 51–NGC 2403–SA 51, each pair of plates measured three times. Independent magnitudes of these sixty stars were also determined by internal measurements of the NGC 2403 plates themselves relative to the adopted primary sequence of Table 1. The mean difference between the primary and the secondary sequence (tied now to SA 51) is $+0.03 \pm 0.01$ mag in the range $20.0 < B < 21.0$; -0.03 ± 0.01 for $21.0 < B < 22.0$; and $+0.02 \pm 0.02$ for $22.0 < B < 22.5$, in the sense primary *minus* secondary. The agreement is excellent and shows that the scale and zero point of the primary sequence have negligible error to at least $B = 22.5$.

Most of the bright photoelectric stars of Table 1 were measured only once except for the following cases: Nos. 39(three 200-inch), 6(three 60-inch), 5[3(60), 2(200)], 10[5(60), 10(200)], 14[5(60), 7(200)], 16[3(60), 4(200)], 13[3(60), 1(200)], 15[2(60), 1(200)], and 7[2(60)]. The mean errors quoted in Table 1 for the photoelectric values

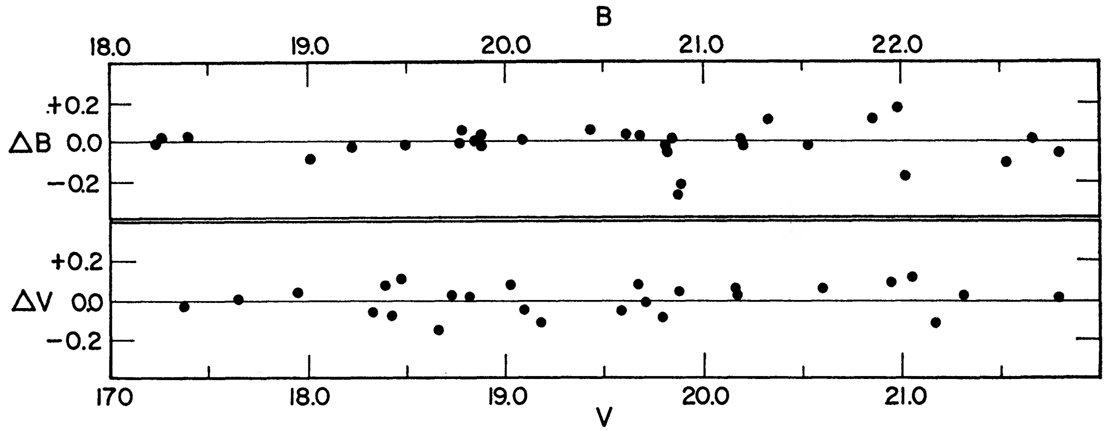

FIG. 2.—Comparison between the adopted and the photoelectric values for stars in Table 1, in the sense "adopted" *minus* photoelectric. The comparison in B is given at the top, and V at the bottom.

fainter than $B = 19.51$ were computed from the internal consistency of the many separate star *minus* sky values which make up each determination. The mean errors of the adopted values were obtained from the internal consistency of the eye estimates from the smoothing process.

Finally, Table 1 lists individual photoelectric values for five faint stars remeasured by pulse-counting techniques near the end of the calibration program where the D.C. values could not be reconciled with the smoothed adopted values. Such unreconciled values are listed in parentheses in Table 1. We believe that the large differences between the photoelectric values themselves and between the mean of these values and the adopted sequence is a result of severe background problems of the type already discussed. The adopted sequence is to be preferred.

b) Secondary Sequences

A sequence of secondary magnitude standards was determined near each variable star by step-scale estimates relative to the adopted sequence. Values for 174 stars were determined from seven blue plates and four yellow plates. Each star was estimated three times on each plate except for those stars near the center of the galaxy in heavy background, where six estimates per star on each plate were made. Table 2 lists the adopted secondary sequences near each of the seventeen Cepheids discussed in § VI. The sequence has been extrapolated from the photoelectric limit at $B = 22.70$ (star 40)

TABLE 2

SECONDARY STANDARDS USED FOR CEPHEIDS AND FOR THE ECLIPSING BINARY V55

Variable	Star*	*B*	*V*†
V1	277	21.88	21.7
	279	22.10	21.8
	278	22.36	20.86
	a	...	...
V3	318*a*	21.97	(21.8
	318*b*	22.54	...
	318*c*(*c*)	23.1	...
	b	...	...
	a	...	...
V4	281	22.31	21.7
	280(*c*)	22.67	(21.8
	b	...	...
	a	...	...
V5	230	21.45	21.09
	229	21.87	21.33
	227	22.27	21.54
	228	22.28	21.52
	228*a*(*b*)	22.50	...
	a	...	...
V6	224	22.12	21.58
	225*b*	22.63	21.74
	225	22.70	(21.8
	225*a*(*c*)	22.95	21.8
	b	...	...
	a	...	...
V8	223	22.02	20.98
	222	22.31	(21.8
	223*a*(*b*)	22.85	(21.8
	a	...	...

Variable	Star*	*B*	*V*†
V15	217	21.78	21.47
	218	21.93	21.45
	220	22.35	21.7
	219	22.48	(21.7
	221(*c*)	22.58	21.8
	b	...	...
	a	...	...
V19	216	21.40	21.34
	215	22.09	21.47
	215*a*(*c*)	22.66	21.49
	b	...	...
	a	...	...
V21	212	22.53	21.7
	213	22.75	21.8
	212*a*(*b*)	23.0	(21.8
	a	...	...
V25	211	21.06	20.37
	208	21.32	21.29
	209	21.51	21.43
	210	21.69	19.87
	210*a*	21.89	...
	210*b*	22.08	...
V29	208	21.32	21.29
	209	21.51	21.43
	210	21.69	19.87
	210*c*(*b*)	22.80	...
	a	...	...
V33	205	21.77	21.39
	206	22.57	21.70
	207	22.57	21.41
	205*a*(*b*)	22.74	(21.8
	a	...	...

Variable	Star*	*B*	*V*†
V34	209*b*	22.66	(21.8
	209*a*	22.72	20.84
	209*c*(*b*)	22.82	(21.8
	a	...	...
V40	203	22.60	21.77
	202	22.75	(21.8
	201(*c*)	22.93	21.62
	b	...	...
	a	...	...
V42	200	22.58	21.7
	200*a*	22.90	21.7
	200*b*(*c*)	23.05	...
	b	...	...
	a (NW of V42)		...
V46	204	22.17	21.62
	203	22.60	21.77
	202	22.75	(21.8
	201(*c*)	22.93	21.62
	b (South of V46)		...
	a (South of V46)		...
V54	322*a*	22.74	...
	322*b*	22.87	...
	322*c*(*c*)	23.1	...
	b	...	...
	a(variable)?		...
V55	217	21.78	21.47
	218	21.93	21.45
	31	21.98	20.18
	220*a*	22.35	21.7
	220	22.45	...
	29	22.67	21.67

* The single-letter designations in parentheses for secondary standards are used in Table A1 for the upper end of the arbitrary Argelander scale, which is described in § VI and in the Appendix.

† The symbol "(" means "fainter than."

to $B \simeq 23.0$ by means of the step scales. The mean internal error of a tabulated magnitude is about ± 0.05 mag. The magnitudes of those stars near the center of the galaxy in heavy background are more uncertain with systematic errors perhaps as high as ± 0.2 mag.

Table 3 lists the additional sequence stars which were used in magnitude estimates for the remaining, non-Cepheid, variables discussed in later sections.

All secondary sequence stars and variables are identified on the large-scale charts of Figures 3–6 (Plates 3–6). The stars are numbered from 200 to 295 in the intermediate and inner regions of the galaxy, and from 300 to 320 in the extreme outer zone. Stars between numbers 245 and 295 lie in regions of heavy background and are undoubtedly affected by the substantial systematic errors quoted above (± 0.2 mag).

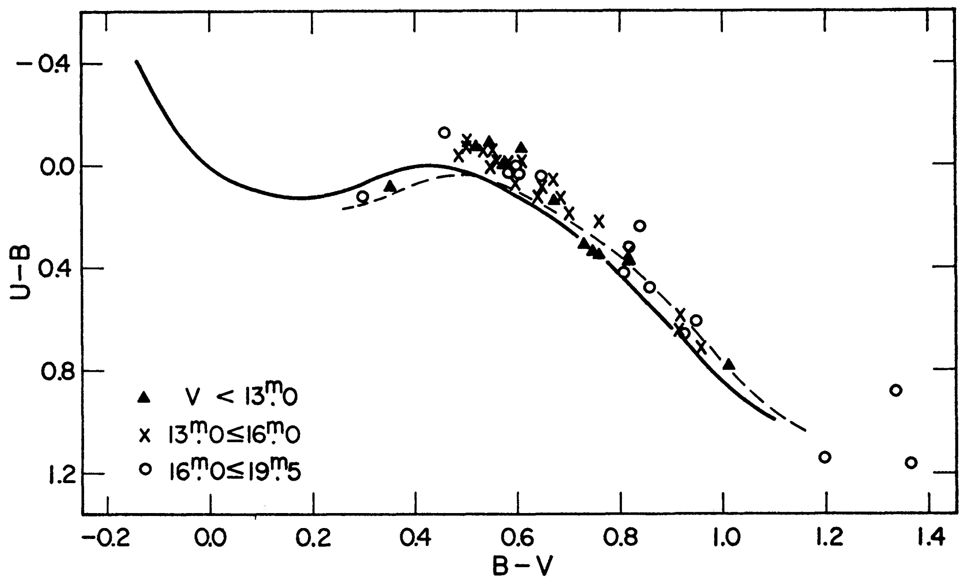

FIG. 7.—The two-color diagram for the photoelectric standards of Table 1 brighter than $V = 19.5$, coded according to magnitude. The solid line is the unreddened relation. The dashed line represents $E(B - V) = 0.06$ mag.

IV. REDDENING DUE TO ABSORPTION WITHIN THE GALACTIC SYSTEM

Figure 7 shows the two-color diagram for the photoelectric standards of Table 1 brighter than $V = 19.5$, coded according to magnitude interval. The standard unreddened relation is drawn as a solid line. The distribution of stars above the standard line in the color interval $0.45 < B - V < 0.7$ cannot be explained by reddening alone, but is undoubtedly caused by a combination of reddening and blanketing. The separation of the two effects, although possible in principle (Eggen and Sandage 1964), is difficult with any precision unless the data are of exceptional quality. Nevertheless, we have used the separation method, adopting the plausible shifts of $\Delta(B - V) = 0.00$, $\Delta(U - B) = -0.10$; and $\Delta(B - V) = +0.04$, $\Delta(U - B) = 0.00$ along the color axes for two separate color intervals centered at $B - V = 0.6$ and $B - V = 0.8$. The results, obtained by simultaneous solution of the two relevant equations, are $E(B - V) = 0.066$ and $E(B - V) = 0.052$, respectively.

A second estimate is obtained by considering only those stars with $B - V > 0.8$ where the effects of blanketing are effectively guillotined by the steepness of the blanketing vector in the two-color plane. These stars give $E(B - V) = 0.06$ as shown by the dashed line shifted along a reddening trajectory by this amount.

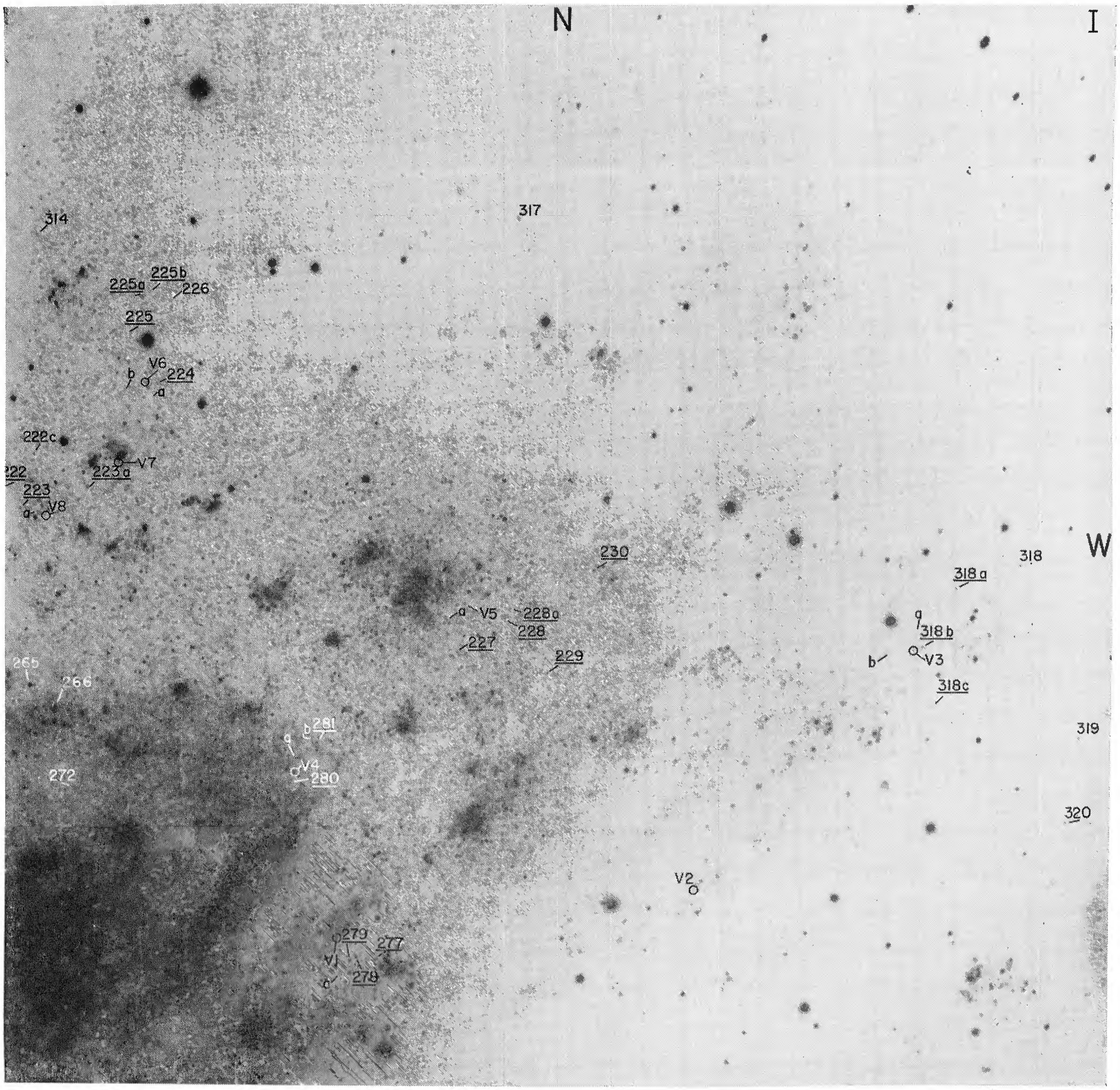

FIG. 3.—Enlargement of Fig. 1 showing Sector I in the N.W. quadrant of NGC 2403. All variable stars, together with the secondary standard stars of Tables 2 and 3, are identified.

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1968ApJ...151..825T

PLATE 4

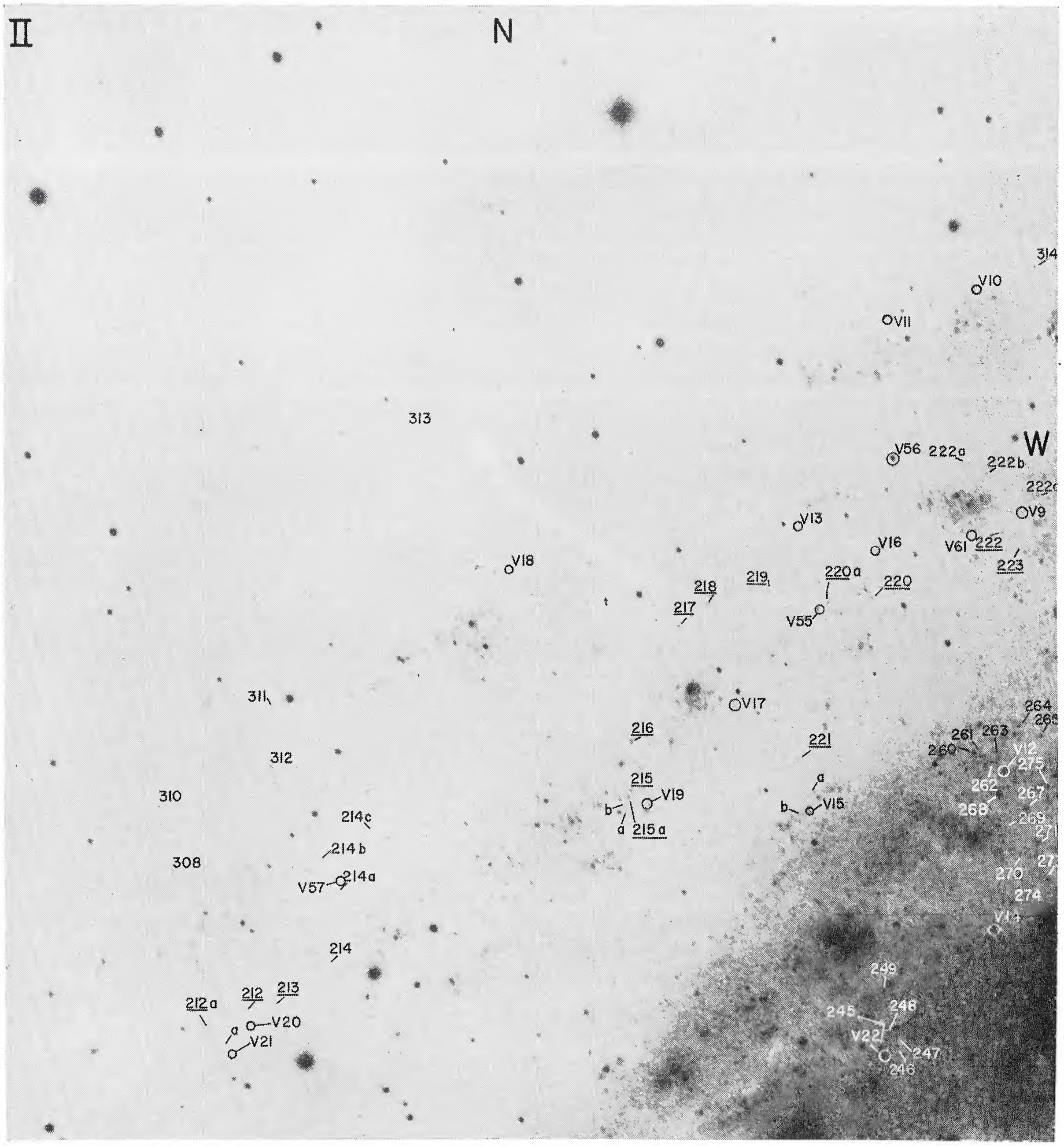

FIG. 4.—Same as Fig. 3 but for Sector II in the N.E. quadrant

TAMMANN AND SANDAGE (*see* page 831)

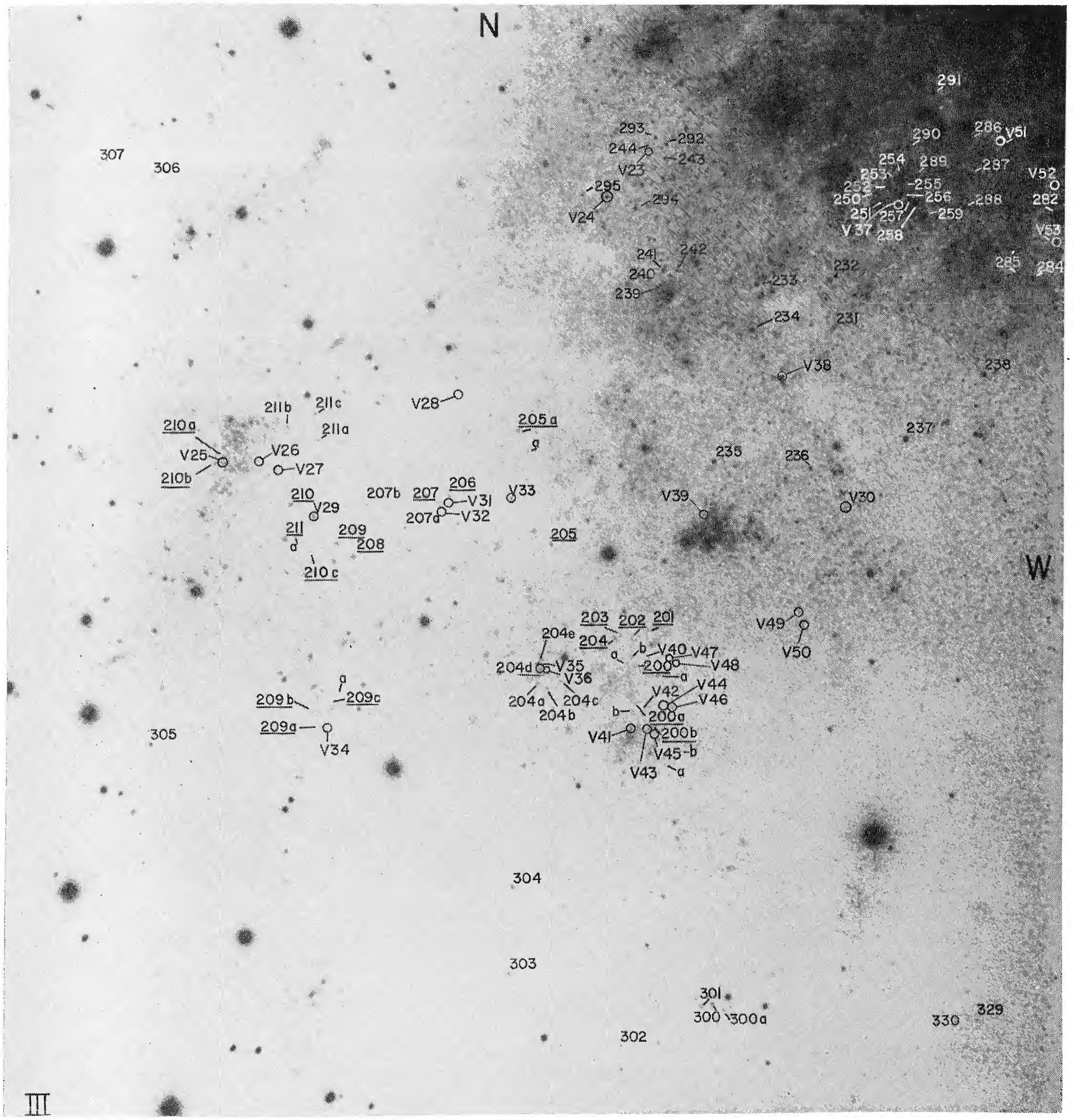

Fig. 5.—Same as Fig. 3 but for Sector III in the S.E. quadrant

Tammann and Sandage (*see* page 831)

1968ApJ...151..825T

PLATE 6

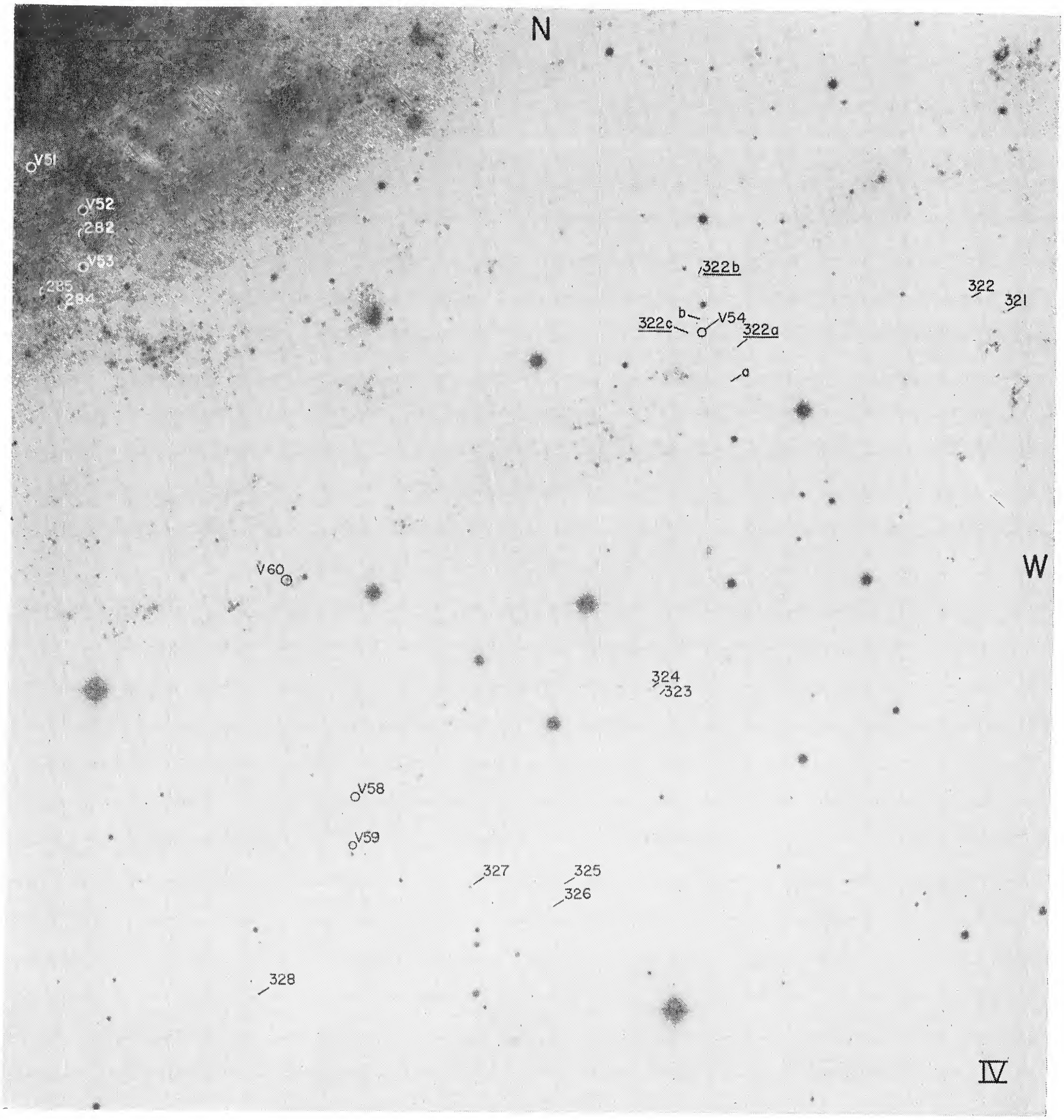

FIG. 6.—Same as Fig. 3 but for Sector IV in the S.W. quadrant

TAMMANN AND SANDAGE (*see* page 831)

1968ApJ...151..825T

TABLE 3

ADDITIONAL SECONDARY STANDARDS IN NGC 2403

No.	*B*	*V*	Quadrant and Remarks*	No.	*B*	*V*	Quadrant and Remarks*	No.	*B*	*V*	Quadrant and Remarks*
204a.....	22.20	21.39	III	248......	21.94	21.14	II, d, b	290......	21.15	21.23	III, b
204b.....	22.86	(21.7	III	249......	20.62	21.17	II, b	291......	20.54	20.63	III, b
204c.....	22.97	21.7	III	250......	21.39	21.31	III, b	292......	20.81	21.13	III
204d.....	22.35	(21.7	III	251......	20.92	21.18	III, b	293......	20.76	20.87	III
204e.....	20.84	21.17	III	252......	21.72	(21.8	III, d, b	294......	20.64	19.80	III, b
207a.....	22.79	20.76	III	253......	19.92	19.89	III, b	295......	20.90	20.82	III
207b.....	22.80	21.8	III	254......	19.21	19.70	III, b	300......	21.58	20.44	III
211a.....	23.0	(21.8	III	255......	20.62	21.15	III, d, b	300a.....	22.64	21.7	III
211b.....	22.80	(21.8	III	256......	21.15	21.16	III, b	301......	21.43	20.58	III
211c.....	22.66	21.8	III	257......	20.83	21.05	III, b	302......	22.14	20.36	III
214......	22.89	(21.8	II	258......	19.10	19.46	III, b	303......	21.82	20.85	III
214a.....	22.56	21.7	II	259......	18.10	......	III, b	304......	21.00	19.78	III
214b.....	22.84	(21.8	II	260......	20.08	20.41	II, b	305......	21.34	20.81	III
214c.....	22.65	(21.8	II	261......	21.03	20.74	II, b	306......	22.58	21.48	III
222a.....	22.78	(21.8	II	262......	21.77	21.22	II, b	307......	21.85	21.8	III
222b.....	22.36	(21.8	II	263......	21.00	20.88	II, b	308......	21.50	21.35	II
222c.....	21.83	21.49	I, II	264......	20.69	20.32	II	310......	21.68	21.5	II
226......	22.71	21.8	I	265......	20.39	20.36	I, II	311......	22.54	20.75	II
231......	20.20	20.38	III	266......	17.70	......	I, b	312......	21.53	21.42	II
232......	19.94	20.06	III	267......	20.12	20.30	II, b	313......	22.22	20.70	II
233......	19.55	18.76	III	268......	19.36	19.49	II, b	314......	22.35	(21.8	I, II
234......	19.88	19.94	III	269......	21.35	21.38	II, b	317......	21.81	21.45	I
235......	20.12	19.44	III, d	270......	21.32	21.24	II, b	318......	21.70	21.41	I
236......	20.22	19.73	III	271......	21.21	21.15	II, d, b	319......	21.65	20.04	I
237......	18.81	18.05	III	272......	20.73	20.45	I, b	320......	22.11	20.31	I
238......	19.38	17.92	III	273......	21.59	21.37	II, b	321......	21.88	21.45	IV
239......	20.79	20.95	III, b	274......	20.32	20.82	II, b	322......	22.44	21.35	IV
240......	20.96	20.49	III, d	275......	20.48	20.74	II, b	323......	22.65	(21.8	IV
241......	21.00	21.27	III	282......	20.61	20.93	III, IV, b	324......	22.22	21.8	IV
242......	20.94	20.83	III	284......	19.99	20.18	III, IV	325......	22.60	21.36	IV
243......	23.1 :	(21.8	III	285......	20.78	20.79	III, IV, b	326......	22.23	20.56	IV
244......	22.32	21.8	III	286......	21.03	21.20	III, b	327......	21.38	19.90	IV
245......	20.70	21.15	II, b	287......	21.28	21.32	III, d, b	328......	22.69	21.5	IV
246......	21.24	20.60	II, b	288......	21.46	21.26	III, b	329......	21.60	21.34	III
247......	21.63	21.39	II, b	289......	21.23	21.20	III, b	330......	22.46	(21.8	III

*Diffuse images denoted by "d"; heavy background denoted by "b."

We adopt $E(B - V) = 0.06 \pm 0.015$ in the subsequent discussion, although the value is unexpectedly low. Hubble's cosecant law, with an absorption half-thickness of $A_B = 0.25$ mag predicts $A_B = 0.52$ or $E(B - V) = 0.13$ at the latitude of NGC 2403 if a normal ratio of $A_B/E(B - V) = 4$ is used. The difference of this prediction from the observed value means either that the normal absorption-to-reddening ratio does not hold in regions out of the plane, as the colors of some high-latitude objects have often suggested, or that NGC 2403 is in a direction of abnormally high transparency. Until the problem of $A_B/E(B - V)$ in high latitudes is solved, we adopt this latter view and accept $A_B = 0.24$ mag, $A_V = 0.18$ mag for the galactic absorption between us and NGC 2403.

V. SEARCH FOR VARIABLES

By the end of 1953, Hubble had marked at least twenty possible variables in NGC 2403, seven of which were definitely Cepheids. We have confirmed all of his suspects, have added new variables from the complete plate material, and have confirmed four of Hubble's suggested periods for the Cepheids.

We wish to comment on the extreme difficulty of work on variable stars at the exceedingly faint light levels encountered here. None of the Cepheids become brighter than $B = 21.2$ at maximum light, and most are fainter than $B = 22.0$ at maximum. Due to the inevitable variation of plate quality caused by differences in seeing, slight inaccuracies of focus, and a small and variable astigmatism of the 200-inch mirror from 1949 to 1955 (typically 0.4 mm difference of focus in the two perpendicular astigmatic planes out of a total focal length of 18644 mm) for declinations north of $+60°$, images near the plate limit show large variations in structure and surface brightness. Slight variations in the grain clumpiness, small changes of emulsion sensitivity, and variations of background density also contribute to the problem. It is often impossible to prove if an actual change of intensity between two plates of different quality has taken place for a given star. Often, inspection of a large fraction of the plate material is necessary before the variability of the faintest stars can be proved. Because of these factors, Hubble's early detection of Cepheids in galaxies outside the Local Group must be considered a remarkable achievement.

When the complete plate material was available, we began a new systematic search for variables over the face of the galaxy. Twenty-seven pairs of plates of comparable quality were blinked, and about eighty suspected variables were marked. All of Hubble's original suspects were rediscovered in this search.

Twenty additional faint suspects were added by successive inspections of small regions of NGC 2403 with a hand magnifier. The complete list of one hundred prospects was reduced to fifty-nine by inspection of all the available plate material. This final sample still contains several stars for which variability could not be established with complete certainty, but these stars have been retained to simplify future work. The fifty-nine variables are identified in Figures 1 and 3–6 (Plates 2 and 3–6).

The variables are separated into the following classes: (1) seventeen definite Cepheids for which light-curves and periods are derived; (2) eight very bright blue variables with irregular light-curves like those found in M31 and M33 (Hubble and Sandage 1953); (3) seventeen bright, very red variables with irregular light-curves similar to the supergiant stars in h and χ Per; (4) one eclipsing binary whose light-curve resembles β Lyrae; (5) sixteen unclassified variables among which are undoubtedly Cepheids of undetermined period. Most of the unclassified variables are fainter than $B = 22.5$ at maximum.

Table 4 contains a summary of the classification of the variables, together with the sector number of Figures 3–6 (Plates 3–6) within which the star is located, and remarks on previous discovery. The type symbols used in the table are: Cepheid (δ), bright blue (BB), bright red (BR), eclipsing (E), unclassified (U), and irregular (I). Details for certain stars are given in later sections under the appropriate class designation.

We cannot accurately determine the completeness of our search. However, from the rediscovery of all of Hubble's variables, and by a thorough search of the available good plates, we estimate that all variables have been discovered which are (1) brighter than $B \simeq 22.0$ mag; (2) have amplitudes greater than 0.5 mag; (3) lie outside the dense background of the central parts of the galaxy; and (4) are uncrowded by companions. Variables which fulfil the same local requirements of background and crowding and which are brighter than $B = 22.5$ at maximum should have been found if their amplitudes are greater than 1 mag. The discovery of variables fainter than this limit must be quite incomplete.

VI. THE CEPHEIDS

Figures 8 and 9 show the light-curves for the seventeen definite Cepheids, arranged in order of period. Magnitude estimates for each variable were made relative to the appropriate secondary standards of Table 2. Three independent estimates were made

TABLE 4

CLASSIFICATION AND FINDING DIRECTORY FOR THE VARIABLES IN NGC 2403

No.	Type	Quadrant	Remarks*	No	Type	Quadrant	Remarks*	No.	Type	Quadrant	Remarks*
1	δ	I		21	δ	II		41..	BR	III	
2	BR	I		22	BB	II		42 .	δ	III	
3	δ	I	H	23.	U, δ?	III		43	BR	III	
4	δ	I		24	Constant	III		44 .	U, δ?	III	
5	δ	I	H	25.	δ	III	H	45 .	U, δ?	III	
6	δ	I	H	26	U, δ?	III	H	46 .	δ	III	
7	BR	I		27 .	BR	III		47 .	U, δ?	III	
8	δ	I	H	28	U, I?	III	H	48 .	U, δ?	III	
9	BR	II		29 .	δ	III	H	49..	U, δ?	III	
10	U, δ?	II		30	BR	III		50	U, δ?	III	H
11	BR	II		31	BR	III		51	Constant	IV	
12.	BB	II		32	BR	III		52 .	BB	IV	
13	U, I?	II	H	33.	δ	III	H	53	BB	IV	
14	BB	II		34	δ	III	H	54	δ	IV	H
15	δ	II	H	35	BB	III		55	E	II	
16	BR	II	H	36	BR	III		56	U	II	
17.	U, E?	II	H	37	BB	III		57..	BR	II	
18.	U, I?	II	H	38.	BB	III	M	58.	BR	IV	
19.	δ	II	H	39	BR	III		59..	U, I?	IV	
20	U, δ?	II	H	40	δ	III	H	60	BR	IV	
								61.	BR	II	

* H and M refer to previous discoveries by Hubble and by N. U. Mayall.

on each plate for each variable in such a way that no memory of previous estimates was available. The mean error of the final magnitudes, listed in Tables A1 and A2 of the Appendix, depends on plate quality, on the regional background density, and on the apparent brightness. The mean error is not greater than ± 0.05 mag for variables brighter than $B = 22.8$, $V = 21.6$ on good quality plates and in regions of light background.

A horizontal line is drawn within the blue light-curve for each variable in Figures 8 and 9. Fainter than this line no numerical magnitude values are available due to differences of background, blends, and lack of suitable nearby secondary standards; rather, only estimates relative to arbitrary standards are available. The ordinate magnitude values do not, therefore, apply for any variable below the line.

Although most of the Cepheids become fainter than the sequence limit at $B = 23.0$ during part of their cycle, intensity estimates fainter than this limit are important for period determinations. An uncalibrated Argelander method was employed, using several very faint comparison stars labeled *c*, *b*, and *a* near each Cepheid, as identified in Figures 3–6 (Plates 3–6). Star *c* is always the brightest of the sequence, and the notation is such that *c2b* means that the star is fainter than *c*, but brighter than *b*, and is 0.2 of the way from *c* to *b*. In cases where the variable is still fainter than the faintest comparison star, an open Argelander scale is used such that *a*4 means fainter than *a* by four arbitrary steps. The estimates are given in the tables of the Appendix.

The adopted elements of the seventeen Cepheids are given in Table 5, listed in order of period. Column (2) gives the uncertainty of the period as determined by inspection of the effect of slightly different trial periods on the conciseness of the light-curve. Column (4) is the epoch of maximum near J.D. 2435500. Columns (5) and (6) list the observed *B* and *V* magnitudes at maximum light. These values, corrected for galactic absorption, are given in columns (7) and (8). Column (9) gives $B - V$ at maximum

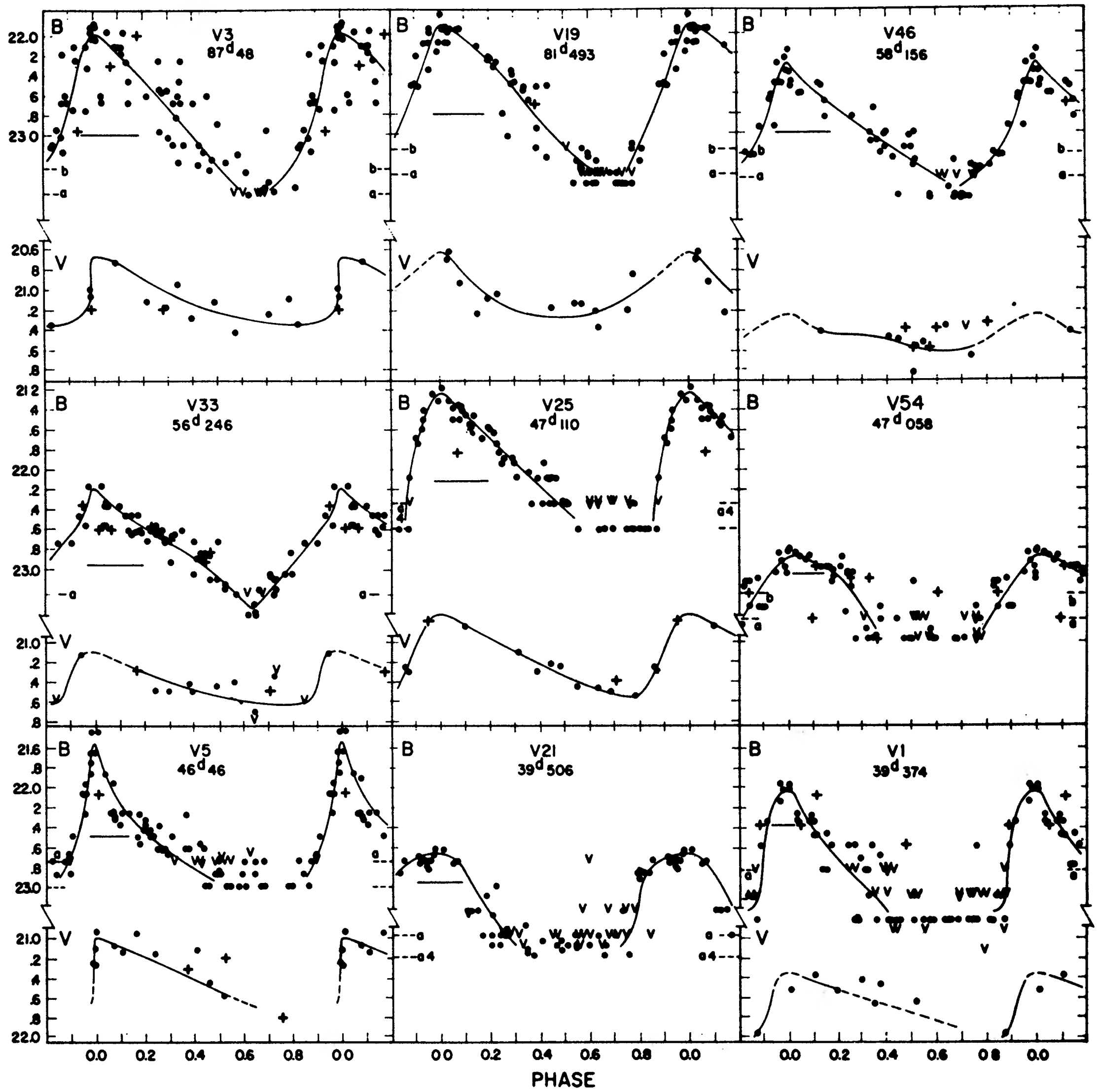

FIG. 8.—Light-curves in *B* and *V* for the first 9 Cepheids of Table 5. The horizontal line within the *B* light-curve of each variable shows the limit fainter than which no numerical magnitude estimates are available, and therefore, in the region where the ordinate values do not apply. The plus signs indicate uncertain values. The inverted carets indicate "fainter than." The magnitudes are from Tables A1 and A2 of the Appendix.

light as corrected only for $E(B - V) = 0.06$ galactic reddening. No correction has been applied for internal reddening in NGC 2403, as justified in § XII. Column (10) shows the difference between column (9) and the ridge line of the period-color relation for Cepheids in galaxies of the Local Group as derived elsewhere (Sandage and Tammann 1968, Fig. 6). A positive sign indicates that the NGC 2403 variables are redder than the normal relation. Columns (11) and (12) list the magnitude residuals in B and V of each variable from the ridge-line of the adopted period-luminosity relation at maximum light

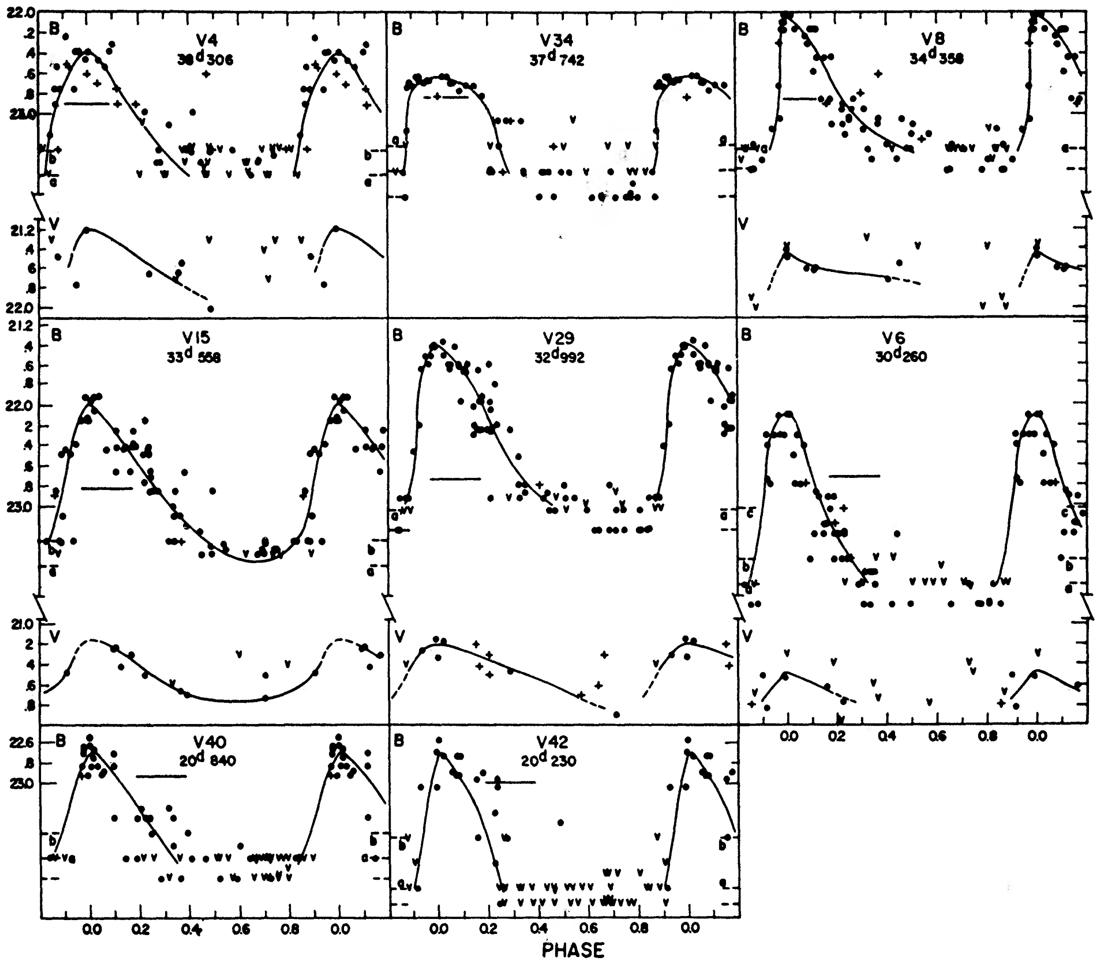

Fig. 9.—Same as Fig. 8 for the remaining 8 Cepheids of Table 5

(Sandage and Tammann 1968, Fig. 5, Table A1), using a true modulus of $(m - M)_0 = 27.56$ for NGC 2403 as derived later. Column (13) lists the background density upon which the Cepheid lies. The abbreviations are l for light, m(medium), h(heavy), vh(very heavy), and bl(blends).

Because nearly all Cepheids decline below the plate limit at minimum light, no information is available on the amplitudes of light variation. To follow the variables through the entire cycle would require plates and a magnitude sequence reaching nearly a full magnitude below what we now possess.

Comments on particular Cepheids are as follows:

V3: The abnormally large scatter of the light-curve is unexplained. It is not due to variations from cycle to cycle, because magnitude estimates within a single cycle contribute to the full scatter.

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TABLE 5

PARAMETERS FOR THE 17 CEPHEIDS

No.	P (days) (1)	$\epsilon(P)$ (2)	log P (3)	Epoch J.D. 2435500+ (4)	B_{max} (5)	V_{max} (6)	$B°$ max (7)	$V°$ max (8)	$(B-V)°$ max (9)	$\delta(B-V)$ (10)	R_B (11)	R_V (12)	Bkg (13)
3	87ᵈ48	0ᵈ2	1.942	36.9	21.97	20.68	21.73	20.50	1.23	+0.48	+0.55	+0.08	ml
19	81.493	06	1.911	28.9	21.91	20.64	21.67	20.46	1.21	+ .50	+0.46	00	ml
46	58.156	03	1.765	15.9	22.31	21.25:	22.07	21.07:	1.00:	+ 43·	+0.75	+ .32:	l
33	56.246	.04	1.750	41.9	22.19	21.11	21.95	20.93	1.02	+ 47	+0 60	+ .15	l
25	47.110	.03	1.673	26.4	21.24	20.73	21.00	20.55	0.45	− 04	−0.46	− 41	m, bl
54	47.058	03	1.673	27 6	22.87	21.6:	22.63	21.4.	1.3:	+ .8.	+0 17	. .	l
5	46.460	.03	1.667	37.9	21.55	21.00	21.31	20.82	0.49	.00	−1.17	− .16	mh
21	39.506	.05	1.597	21.2	22.67	21.5:	22.43	21.4:	1.0:	+ .6:	+0.83	+ 14:	l
1	39.374	005	1.595	13.8	22.02	21.36	21.78	21.18	0.60	+ 16	+0 18	.00	vh
4	38.306	.1	1.583	46.0	22.38	21.20	22.14	21.02	1.12	+ .69	+0.51	− .19	vh
34	37 742	005	1.577	28.3	22.62	21.52:	22.38	21.34:	1.04.	+ .62:	+0 72	+ .11.	l, bl
8	34.354	.01	1.536	12.2	22.01	21.45	21.77	21.27	0.50	+ .10	+0 04	− .09	m
15	33.558	.04	1.526	27.3	21.98	21.15	21.74	20.97	0.77	+ .38	−0 02	− 43	mh
29	32.992	02	1.518	27.9	21.41	21.20	21.17	21.02	0.15	− .24	−0.61	− .39	l
6	20.260	.005	1.481	19.2	22.12	21.49	21.88	21.31	0.57	+ .20	0 00	− .21	l
40	20.840	.008	1.319	28.1	22.70:	21.8.	22.46:	21.6:	0.9:	+ .6:	+0.19·	− 4:	ml
42	20.230	0.002	1.306	27.8	22.70:	21.7.	22.46:	21.5:	1.0:	+0.7	+0 05:	−0.5:	ml

V25: This brightest of all Cepheids lies at the edge of a bright patch of a spiral arm. Two neighboring stars, 3″ distant, are of comparable brightness and cause difficulties in the magnitude estimates fainter than $B \simeq 22.1$. The star cannot be followed with any accuracy below $B = 22.6$. There is no reason, however, to expect inaccuracies in B(max) and V(max).

V54: This faintest and reddest of all variables lies in the center of the best-defined outer spiral arm. The star undoubtedly suffers from local obscuration. The tabulated magnitudes are the mean of four estimates. The period is not beyond doubt.

V1 and V4: Discovered by Hubble, these variables are the innermost Cepheids yet known in this Galaxy. Hubble believed them to be novae from his study of the partial material available in 1952, but later rejected this possibility. The very heavy background makes the magnitude estimates extremely difficult. The period of V4 is not beyond doubt.

V34: A brighter comparison, 2″ distant, makes magnitude estimates difficult fainter than $B = 22.8$. However, B(max) should be accurate.

V8: Situated in a spiral arm and surrounded by faint companions. Magnitude estimates fainter than B(max) and V(max) are uncertain on plates of poor seeing.

V15: Although on rather heavy background and surrounded by faint, nearby stars, this Cepheid is one of the few for which the light-curve is determined through minimum. However, the minimum lies, as in all other cases, well beyond the photoelectric sequence.

V29: This is the bluest of the Cepheids by a very large margin. Although the abnormal color could be caused by an unseen bright blue companion, such cannot be the case here because the variable has an amplitude of at least $A_B = 1.6$ mag which is close to the maximum amplitude of $A_B \simeq 1.9$ mag at $\log P = 1.52$ (Kraft 1961, Fig. 5) for galactic Cepheids. Although the star is among the brightest of the Cepheids in B(max), we accept the star as single and use it in the upper-envelope fit to the P-L relation in § XII.

V40: Due to its faintness, B(max) is not well determined.

V42: The period is not beyond doubt because the star is below the plate limit (invisible) on most of our available plate material.

VII. THE VERY BRIGHT BLUE VARIABLES

a) Light-Curves

Five certain (Nos. 12, 22, 35, 37, and 38) and three probable (Nos. 14, 52, and 53) bright blue irregular variables of the M31 and M33 type (Hubble and Sandage 1953) have been found in NGC 2403. Light-curves in B for the interval from 1910 to 1963 are shown in Figure 10 for seven of the stars; the eighth member is the remarkable variable V12 illustrated in Figure 11. The individual B and V magnitude values are listed in Tables A3 and A4 of the Appendix. The magnitudes before 1950 are determined from the 60-inch reflector plates, and it is interesting to note that the limiting magnitude of that telescope was about $B \simeq 21.5$ in the early days of its operation.

The light-curves of V22, V35, V37, and V38 are quite similar. They have relatively small amplitudes of about 2 mag and characteristic fluctuation times of several years. There is also clear similarity in light variations and colors between these variables and their prototypes in M31 and M33. Values of $B - V$, obtained from the estimated V magnitudes of Table A4 in the Appendix, combined with interpolated B magnitudes from the light-curves, are indicated in Figures 10 and 11.

The colors and magnitudes show that the stars are F supergiants in the most extreme upper region of the H-R diagram where incipient pulsational instability, perhaps of the type discussed by Ledoux (1941) and by Schwarzschild and Härm (1959), is present. The stars are presumably very massive and may be just below the mass limit of disruptive instability ($M \simeq 60\, M_\odot$). There are no stable stars, either in this galaxy or in M33 and M31, brighter than the brightest of these variables.

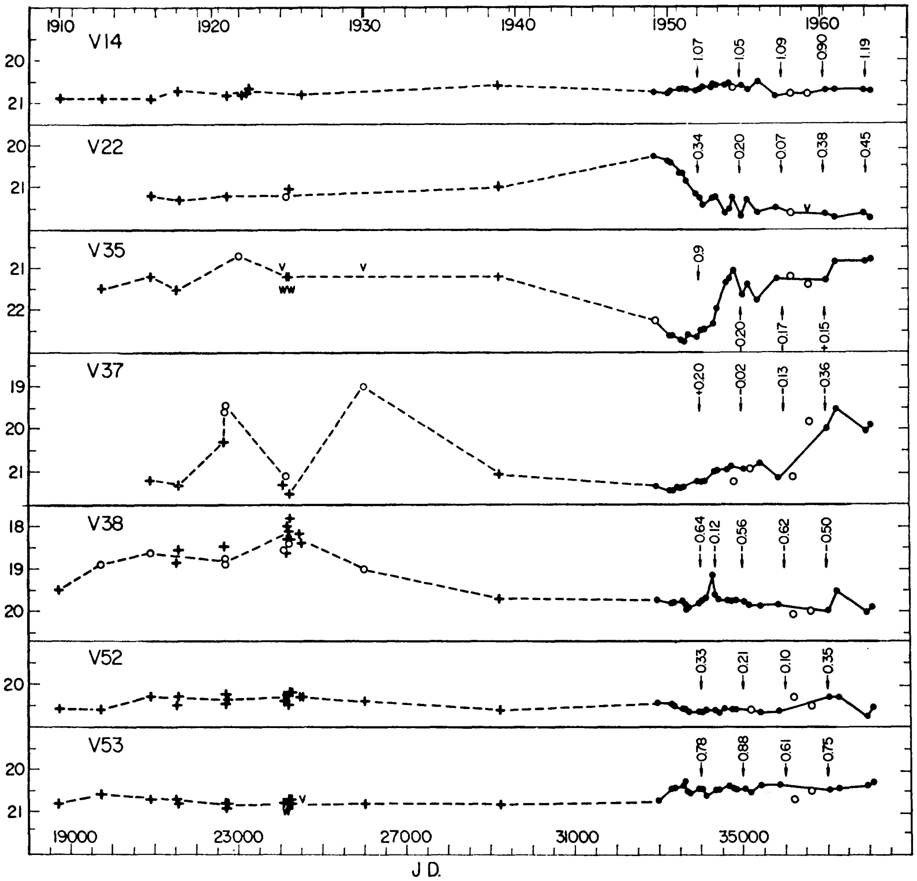

FIG. 10.—Light-curves in *B* for 7 of the 8 bright blue irregular variables listed in Table 6 from 1910 to 1963. The magnitudes are from Table A3 of the Appendix.

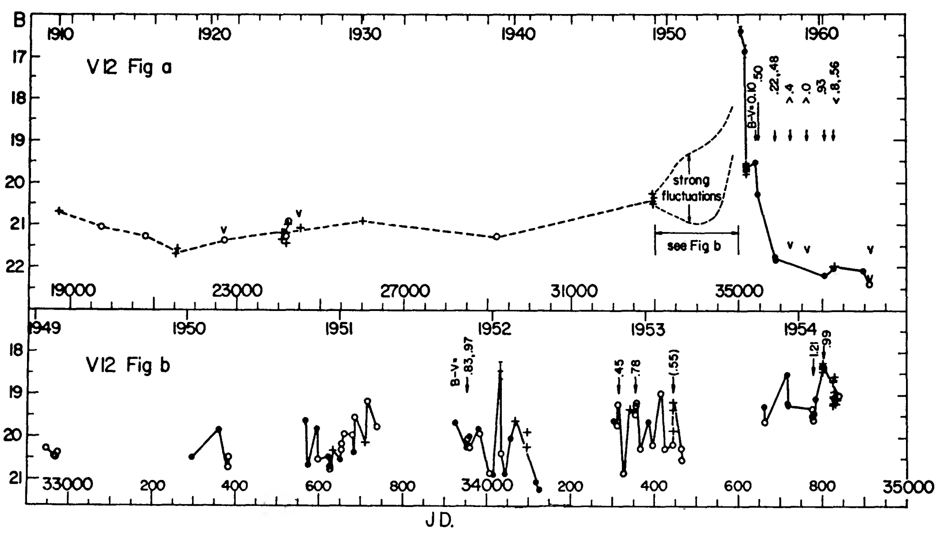

FIG. 11.—Light-curve in *B* for the bright blue irregular variable V12. The upper panel illustrates the variation from 1910 to 1963. The lower panel shows the variations from 1949 to 1954 on an expanded time scale.

The variations of V14, V52, and V53 are not as pronounced as for the variables just discussed. The fluctuations are small, with a total amplitude of only 0.5 mag. Each plate was estimated five times, and although we are rather convinced that the light variations are real, the case is not proved conclusively.

The most remarkable of the variables is V12 shown in Figure 11*a* and *b*. The star behaved in a normal manner, fluctuating irregularly around $B \simeq 21$ with a total range of about 1 mag until 1950, at which time large, short-period variations began which lasted until the beginning of 1955. During the 4-year interval beginning in 1950, the star would often vary by 1 mag between observing periods of 10 days. The variations were so unusual in 1951, 1952, and 1953 that we believed at first that the star might be a field RR Lyrae variable superposed upon the field. In 1954, a special series of plates was obtained in a 4-night interval with the 60-inch (Plates S-247-S to S-266-S in March, 1954; see Table A3) to check for night-to-night variations. Although the seeing was exceedingly poor, the star was visible on all plates and seems to vary by about 0.5 mag from night to night, although this result is not beyond doubt.

During the 7-month interval between the last plate in April, 1954, and the first plate of the 1954/1955 season, taken on November 2/3, 1954, V12 underwent a major outburst, reaching $B = 16.46$. The absolute magnitude of V12 was $M_B = -11.3$ on this date, adopting an apparent blue modulus of $(m - M)_{AB} = 27.80$ as derived later, but in view of the subsequent rapid decline, the star may have been even brighter before this time. During the outburst, V12 was by far the brightest object in NGC 2403.

The variable declined rather smoothly at a rate of about 0.20 mag/month during the first 825 days after the observed maximum, until it reached $B = 21.8$ in February, 1957. The star then dropped below $B = 22$ and has remained fainter than this level on all subsequent plates.

V12 is similar in some respects to the remarkable galactic star η Carinae. The history of this star has been reviewed by Gratton (1963), where references to the extensive earlier literature can be found. The star η Car reached apparent visual magnitude of -1 in 1843, remained near $V = 0$ until 1855, after which it declined over a period of 15 years to $V \simeq 8$. After 1941 it began a steady increase from $B \simeq 8.5$ in 1940 to $B \simeq 7.1$ in 1952 (de Vaucouleurs 1952; de Vaucouleurs and Eggen 1952; O'Connell 1956; Gratton 1963). Adopting Gratton's apparent visual modulus of $(m - M)_{AV} = 11.6$ gives $M_V(\text{max}) = -12.6$ for η Car, which is of the same order as V12 in NGC 2403.

The general spectral characteristics of η Car are also similar to the bright blue variables in galaxies. Bok (1930) concluded from his study of objective-prism plates taken at Arequipa between 1889 and 1893 that the spectral type of η Car was cF5. A subsequent analysis by Whitney (1952) supports this conclusion. The spectral type assigned by Hubble and Sandage (1953) to the variables in M31 and M33 was supergiant F, with P Cyg absorption characteristics for M33 Var B, as are also present in η Car (Gratton 1963).

Finally, the color of η Car was $C_P = +0.42$ in 1952 (de Vaucouleurs and Eggen 1952), which is consistent with the colors of the bright blue variables in NGC 2403, M31, and M33.

b) Absolute Magnitudes

Table 6 lists some of the photometric properties of these variables, calculated with an apparent blue modulus of $(m - M)_{AB} = 27.80$ for NGC 2403. The mean blue absolute luminosity at maximum, excluding V12, is $\langle M_B(\text{max}) \rangle = -8.0 \pm 0.8$ (AD), which is considerably fainter and has a larger dispersion than the variables in M31 and M33 for which the following new calibration is available. Direct photoelectric calibration (Sandage, unpublished) of the sequence stars used by Hubble and Sandage in M33 shows that $B - m_{\text{pg}}(\text{HS}) = +0.1$ near $m_{\text{pg}} = 15.5$, which is the relevant range. This correction, together with the apparent blue modulus of $(m - M)_{AB} = 24.84$ for M31, based on the definitive work of Baade and Swope (1963), together with $(m - M)_{AB} =$ 24.74 for M33 gives M_B(max) = −9.1 for M31, V19; −9.2 (M33,V2); −8.9 (M33,*A*); −9.5 (M33,*B*); and −9.3 (M33,*C*) for a mean of $\langle M_B(\max)\rangle = -9.2 \pm 0.16$ (AD).

Unpublished data also now exist for seven members of the class in M81. If $(m - M)_{AB} = 27.8$ applies, then the individual M_B(max) values for these new variables are −7.3, −9.1, −9.4, −8.4, −7.4, −8.3, and −8.3 giving $\langle M_B(\max)\rangle_{M81} = -8.3 \pm 0.6$ (AD), which again is considerably fainter than for M31 and M33. It is, however, interesting to note that the *brightest* variable in each galaxy defines a more comparable sample. The values for the four galaxies in question are M_B(max) = −9.5 for M33, *B;* −9.6 (NGC 2403,V38); −9.1 (M31,V19); and −9.4 (M81).

We can summarize the results as follows. The twenty members of the class now known (one in M31, four in M33, eight in NGC 2403, and seven in M81) suggest that (1) the range of M_B(max) is about 3 mag, and (2) M_B(max) for the first-ranked variable appears to be a good statistic with $\langle M_B(\max)\rangle_{1st} = -9.4 \pm 0.2$ (AD), if the occasional

TABLE 6

DATA FOR THE BRIGHT BLUE IRREGULAR VARIABLES

VARIABLE	*B* (max)	DATE AT MAX.	*B* (min)	DATE AT MIN	AMPL	*B−V**		M_B (max)†
						Bluest	Reddest	
V12	16 46	Nov. 3, 1954	(22 40)	Mar 19, 1963	5 94	+0 04	+1 15	−11 3
V22	20 18	Feb. 26, 1949	21 76	Mar. 21, 1963	1 6	+ 01	+0 39	− 7 6
V35	20 7	Jan. 5, 1921	22 90	Feb. 3, 1951	2 2	− .26	+0 8	− 7 1
V37	19 0	Jan 22, 1930	21 48	Apr. 13, 1950	2 5	− .42	+0 14	− 8 8
V38	18 2‡	Mar. 1, 1925	20 08	Jan 16, 1958	1 9	− 70	−0.24	− 9 6
V14	20 49	Dec. 15, 1955	20 90	Feb. 1, 1957	0 5	+ 84	+1 03	− 7 3
V52	20 27	Dec. 23, 1960	20 73	Nov. 5, 1962	0 5	+ 04	+0 29	− 7 5
V53	20 26	Dec. 12, 1950	20 8	Long	0 5	+0 55	+0 82	− 7.5

* Corrected for galactic reddening of 0 06 mag.

† Based on the observed *B*(max) and an apparent blue modulus of $(m-M)_{AB}$ = 27 80

‡ This value is the mean of the plotted values near March 1, 1925, shown in Figure 10

spectacular bursts of individual stars (NGC 2403,V12; η Car) are ignored. If conclusion (2) is valid, these stars can serve as rough distance indicators for galaxies out to moduli of $(m - M)_{AB} \simeq 30.5$.

VIII. RED SUPERGIANT IRREGULAR VARIABLES

Seventeen variables were found which fulfil the conditions: $V(\max) < 21.05$, $B - V > 1.5$. The stars are exceedingly red and are very bright intrinsically with M_V(max) brighter than −6.5, adopting an apparent visual modulus of $(m - M)_{AV} = 27.74$ as later derived. The variables form part of a larger population of non-variable red supergiants whose progenitors are the brightest main-sequence O and B stars. Such stars, whose somewhat fainter analogues in the galactic system are the supergiants of h and χ Persei, have been found in all galaxies of the Local Group so far studied (Humason and Sandage 1957 in M33; Walker 1964, 1967 in M33; Hodge 1961, 1965 in LMC; Arp 1961 in SMC; and Kayser 1967 in NGC 6822).

Table 7 summarizes the photometric data for the red variables in NGC 2403. The individual magnitude estimates are given in Table A4 of the Appendix. The stars are of Population I as shown by their concentration near the spiral arms.

Similar variables are known in the LMC, SMC, NGC 6822, and M33. Only small-sample fields have been searched in LMC (Shapley and Nail 1948, 1955), SMC (Shapley and Nail 1951), and M33 (Humason and Sandage 1957), but the entire field of NGC 6822 has been searched by Kayser (1967). To the extent that the partial search across the LMC and SMC is representative, mean absolute luminosities of the brightest red supergiant variables can be obtained and tested as a distance criterion.

The agreement in M_V(max) and M_B(max) for the first-ranked red variable in LMC, SMC, and NGC 6822 is quite good. The brightest red irregular in SMC is HV 11423 at B(max) = 12.9, V(max) $\simeq$ 10.9 (assumed), which, with apparent distance moduli of $(m - M)_{AB} = 19.05$, $(m - M)_{AV} = 19.00$ (Sandage and Tammann 1968), give M_V(max) = −8.10, M_B(max) = −6.15. The brightest red variable listed in the LMC is HV 5582 (Shapley and Nail 1948, 1955) with B(max) = 12.5, V(max) $\simeq$ 10.5 (assumed), giving

TABLE 7

ELEMENTS OF SEVENTEEN VERY RED, SUPERGIANT IRREGULAR VARIABLES

No.	B (max)	V (max)	ΔV	$B_m - V_m$	Quadrant	Location	M_V (max)*	M_B (max)†
V2.	(23	20 94	0 54	>2 0	I	In spiral arm	−6 80	...
V7.	(23	20.30	1.17	>2.7	I	Close to H II	−7 44	...
V9.	22 02	20.27	0 7	1 75	II	In spiral arm	−7 47	−5 78
V11.	22 80	20 88	0 53	1 92	II	In spiral arm	−6 86	−5 00
V16	22 62	20 17	1 26	2 45	II	Isolated	−7 57	−5 18
V27	(23	21.05	0 35	>1 8	III	Near arm	−6 69	...
V30	22 9	20 41	0 6	2 5	III	In spiral arm	−7.33	−4 9
V31.	22 9	20.95	0 5	1.9	III	... ...	−6 79	−4 90
V32	22 8	21 04	0 5	1 8	III	13″ from V31	−6.70	−5 00
V36.	(22 85	20.74	1 05	>2 1	III	In arm	−7 00	...
V39	(22 6	20.78	>0 6	>1 8	III	Near H II region	−6 96	...
V41	22.40	19.98	0 43	2 42	III	Near H II region	−7.76	−5 40
V43	22 50	20.45	0 85	2 16	III	18″ from V41	−7 29	−5 30
V57	22 50	20.05	1 14	2 45	II	Isolated	−7 69	−5 30
V58	22.70	21.05	0 5	1 65	IV	In outer arm	−6 69	−5 10
V60	21.7:	20 20	1 05	1 5:	IV	In spiral arm, within faint nebulosity, nearby blue companions	−7 54	−6 1:
V61	23 0	20 51	0 7	2 5	II	Inner edge of spiral arm	−7 23	−4.8

* M_V based on an apparent visual modulus of $(m-M)_{AV}=27.74$.
† M_B based on an apparent blue modulus of $(m-M)_{AB}=27.80$

M_V(max) = −8.10, M_B(max) = −6.15. Kayser's work (1967) in NGC 6822 gives V18 as the brightest variable with V(max) = 16.76, B(max) = 19.17, $(m - M)_{AV} = 24.56$, $(m - M)_{AB} = 24.83$ giving M_V(max) = −7.80, M_B(max) = −5.66. These calibrations, especially in the LMC and SMC, can be improved by a complete search over the face of the clouds and by photoelectric measurement, but for the moment we can adopt $\langle M_V(\text{max})\rangle_{1st} = -8.00 \pm 0.1$, $\langle M_B(\text{max})\rangle_{1st} = -6.00 \pm 0.2$ as working values for the brightest red irregular variable, and check for consistency in other galaxies.

The brightest variable of this type in V wavelengths in NGC 2403 is V41 at V(max) = 19.98, giving $(m - M)_{AV} = 27.98 \pm 0.1$ if we adopt M_V(max) = −8.00. The brightest reliable variable in B wavelengths is V9 at B(max) = 22.02 giving $(m - M)_{AB}$ = 28.02 ± 0.2. These apparent moduli are remarkably close to $(m - M)_{AV} = 27.74$, $(m - M)_{AB} = 27.80$ which are later derived from the Cepheids in NGC 2403, and this agreement shows that the supergiant red irregulars have promise as good distance indicators. All effort will be made to improve the calibration in the coming year by more detailed work in the LMC and SMC.

The number of observations required to determine $V(\max)$ and $B(\max)$ for the red irregular variables is prohibitive in most galaxies, and a simpler criterion using non-variable red stars is desired. The discovery of the reddest and brightest supergiants in any resolved galaxy is moderately easy by blinking red and blue plates. If the upper luminosity of these stars is well defined, as is suggested by the foregoing results on the variables, and assuming that the variables and non-variables attain nearly the same luminosity as indicated by Kayser's complete work (1967, Fig. 2) on the C-M diagram of NGC 6822, then the red supergiants with $B - V > 1.5$ themselves can be used as distance indicators, whether they are variables or not. Kayser's diagram shows that an upper envelope of the distribution of such red stars in NGC 6822 exists at about $V = 16.6$ or $M_V^\circ = -8.0 \pm 0.3$.

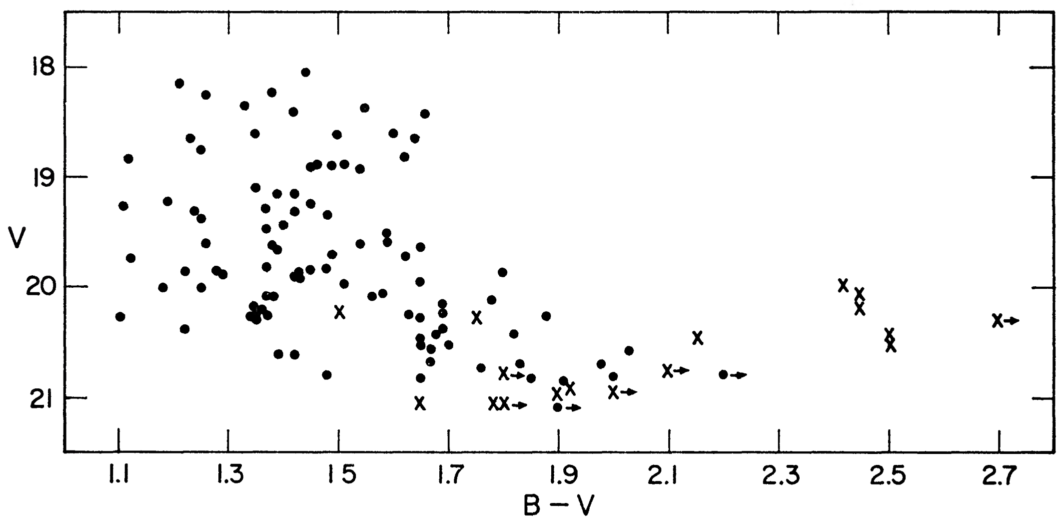

FIG. 12.—The color-magnitude diagram for the reddest stars in the neighborhood of NGC 2403, listed in Table 8. The red irregular variables listed in Table 7 are shown as crosses. Those variables which are invisible at maximum on blue plates are marked with arrows, indicating that the $B - V$ values are redder than the plotted value. We assume that stars bluer than $B - V = 1.9$ are foreground stars from our Galaxy.

We have made a blink survey for the reddest stars in NGC 2403 and have determined colors and magnitudes of 114 such stars by step-scale estimates on four yellow plates and three blue plates. The results are shown in Figure 12 and Table 8. The stars are identified in Figure 13 (Plate 7) which is from a limiting yellow exposure with the 200-inch. The brightest of the red supergiant stars appear at $V = 19.85$, which gives $(m - M)_{AV} = 27.85$, using $M_V = -8.00$ for the upper limit. This modulus is in excellent agreement with $(m - M)_{AV} = 27.74$ derived from the Cepheids.

We believe this method of distance determination has great power for other resolved Sc and Irr galaxies because the red supergiants are easy to locate and to measure. If future work continues to show that the upper limit is near $M_V = -8.0$ and is stable, then distance moduli as great as $(m - M)_{AV} = 29.0$ can be reached, and the method will have important use in the redetermination of the Hubble constant.

IX. THE ECLIPSING BINARY

One eclipsing binary, V55, has been found with a period of $6^{d}06702$. The light-curve is shown in Figure 14 and is of the β Lyrae type. The magnitude estimates are given in Table A3 of the Appendix. The maximum brightness of $B = 21.77$ mag indicates, for equal components, that each star has an absolute magnitude of $M_B = -5.3$, adopting

1968ApJ...151..825T

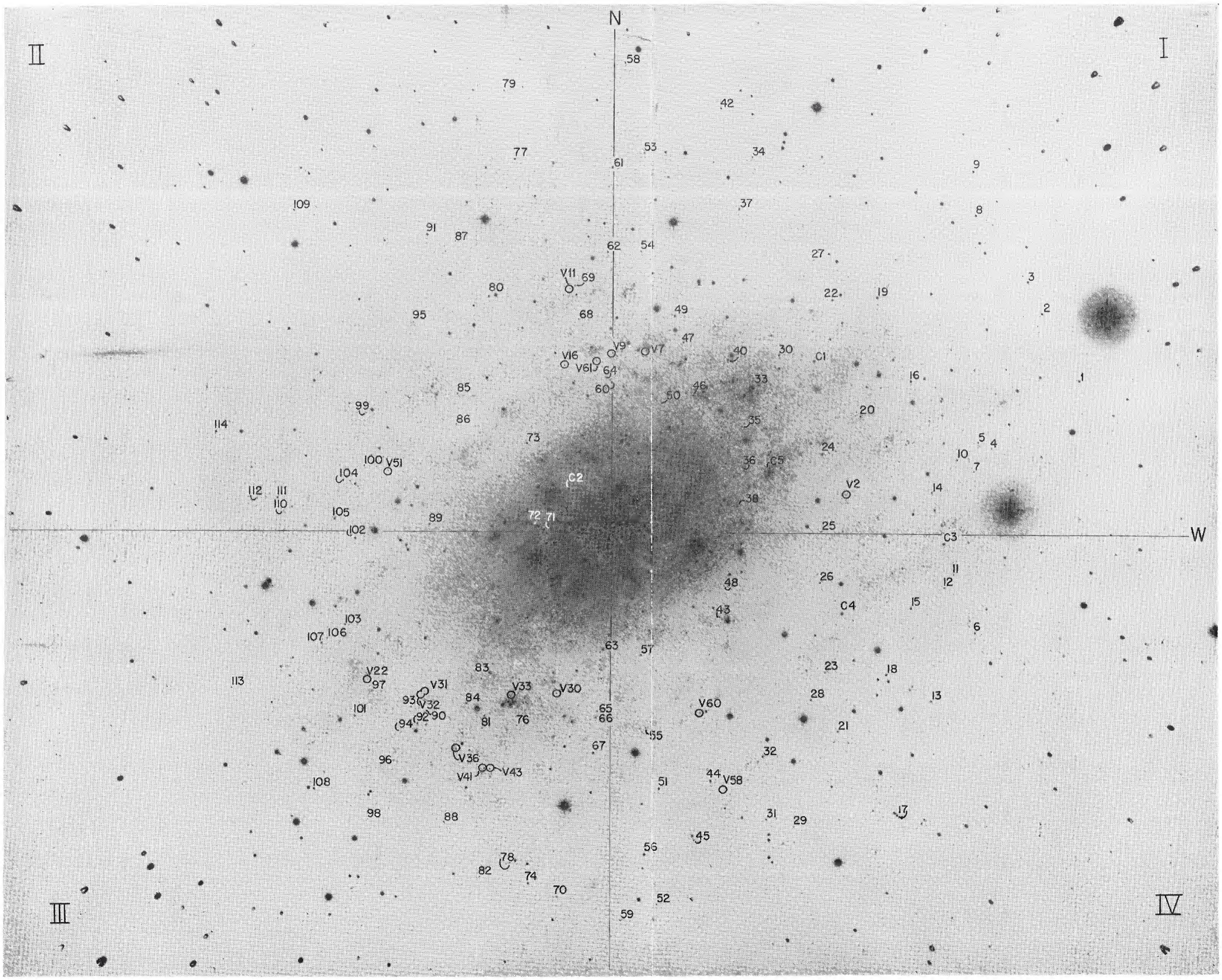

FIG. 13.—Identification chart for the red stars of Table 8, together with the red irregular variables of Table 7, and the five clusters listed in Table 11. The reproduction is from a 40-min exposure on Eastman 103aD + G11 emulsion with the 200-inch.

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TABLE 8

RED STARS IN NGC 2403 WITH $B-V \geq 1$ 10

No.	V	B−V	No	V	B−V	No	V	B−V
1 . .	19 14:	1 77:	39 .	20 80	1 48	77. .	19 27	1 11
2	19 38	1 46:	40 . .	19 70	1 49	78†	20 38	1 22
3	19 08	1 62:	41 .	18 90	1 49	79	20 05:	1 65:
4..	20 51	1 65	42	19 76:	1 45:	80	18 88	1 46
5†	20 06	1 58	43.	20 25	1 37	81.	19 85	1 80
6.	19 86	1 43	44*	19 16	1.42	82†	20 42	1 82
7†	20 39	1 69	45	20 27	1 10	83	20 74	1.76
8	18 88:	1.57:	46	19 72:	1 27:	84	19 48	1 37
9	19.10:	1.70:	47	20 23	1 35	85	20.26	1 88
10	19 44	1 40	48	19 97:	1 38	86	20.25	1 63
11	20 60	1 39	49	18 65	1 64	87.	20.57	2 03
12.	20 01	1 18	50	20 09	1 56	88†.	19.85	1 22
13..	19 66	1 39	51	18 35	1 33	89	19 60	1 26
14.	20 24	1 69	52	20 20	1 36	90	19 85	1 28
15.	18 88	1 51	53.	20 47	1 65	91	18 15	1 21
16.	18 60	1 60	54†	20 16	1 69	92	19 63	1.38
17.	19 10	1 35	55.	20 27	1 65	93.	20 08	1 38
18	19 15	1 39	56*	18 75	1 25	94†	20 85	1 91
19 .	18 54	1.26	57	20 24	1 34	95†	20 61	1 42
20	19 61	1.54	58	19 80:	1 72:	96†	20 82	1 85
21	20 39	1 43	59	19 96:	1 21:	97†	19 95	1 65
22	19 50	1 59	60	19 32	1 42	98.	20 66	1 67
23	19 98	1 51	61.	18 42	1 66	99†	20 82	1 65
24	18 22	1 38	62*	19 83	1 37	100	19 87	1 29
25.	20 02	1 25	63	18 05	1 44	101	19 39	1 25
26* .	19 71	1 62	64	21 09	>1 9	102	19 21	1 19
27	20 69	1 98	65	20 07	1 37	103	19 82	1 48
28.	19 59	1 59	66.	19 91	1 42	104	18 82	1 62
29†	20 52	1 70	67*	18 37	1 55	105	18 83	1 12
30.	18 65	1 23	68*	20 12	1 78	106	20 42	1 68
31†	19 84	1 45	69*	19 74	1 12	107	18 60	1 35
32	18 94	1 54	70	20 25	1 35	108	18 61	1 50
33	19 64	1 65	71	20 07:	1 31:	109	19 94:	1 36:
34	20 04	1 85:	72	19 90:	1 43:	110	20 79	>2 2
35 .	20 54	1 67	73	18.90	1 45	111	19 31	1 24
36	20 50	1.31:	74	19 29	1 37	112	20 80	2 0
37	19 35	1.48	75.	20 29:	1 76:	113	20 27	1 35
38	18 40	1.42	76‡	20.70	1.83	114	19 25	1 45

* p.e. standard; independent estimates
† Secondary standard; independent estimates.
‡ Possibly variable.

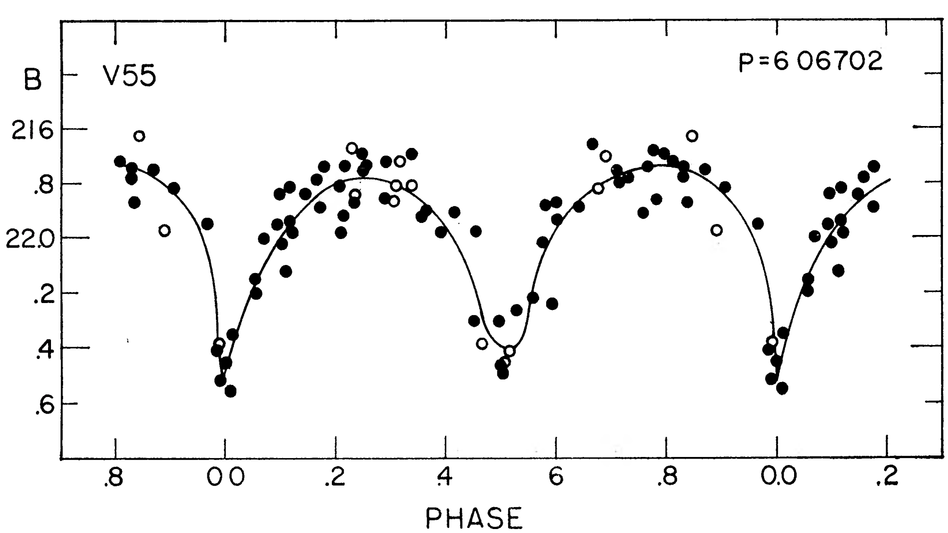

FIG. 14.—Light-curve in B for the eclipsing binary V55

$(m - M)_{AB} = 27.80$. Similar eclipsing binaries are known in M31 (Gaposchkin 1962*a*, *b;* Baade and Swope 1963, 1965) and in the Magellanic Clouds (Shapley and Nail 1953; Russell 1956).

X. UNCLASSIFIED VARIABLES

Table 9 summarizes the available information on sixteen variables whose type could not be determined. These stars are generally so faint that no individual magnitude values are listed in the tables of the Appendix because, on most plates, the variables are invisible. Only three of the stars, V28, V59, and V56, are seen on the yellow plates, indicating that most of the variables are not particularly red. Extensive attempts to find periods proved to be unsuccessful, but the presence of several maxima, as listed in Table 9, suggests that some of the variables are Cepheids.

TABLE 9

SIXTEEN UNCLASSIFIED VARIABLES

Variable	*B* (max)	Type	J D of Maximum (2400000+)	Remarks
V10	22 80	Cepheid?	33980 9, 34778 7, 38109 7	Small amplitude
V13	22 8	Irr?	34058 7, 35456 9, 35874 8, 38107 7	Small amplitude, changes within 3 days
V17	22 50	Eclipsing?	Min.: 33361 8, 33569 0, 33598 0, 33650 8	Near nebulosity
V18	22.85	Irr?	34125 7, 34454 7	
V20	22 9	Cepheid?	33660.8, 33681 8, 34356 9, 34454 6, 34719 9	
V23	22 8	Cepheid?	33956 9, 34327 9, 35049 9, 38109.7	Heavy background
V26	22 75	Cepheid?	33624.9, 33681.8, 33960.0, 33980 9, 34719 9, 38107.7	
V28	21 90	Irr?	32969 7/73 7, 34118 7, 34778 7/802 6	*V*(max) = 21.73 on J.D. 2434 779 7
V44	22 9	Cepheid?	33650.8, 34015.9, 34661 0, 34718 8, 34780 7, 35874 8	
V45 .	23 0	Cepheid?	33685.8, 33983.9, 34125.7, 34717.8/19.8, 34779.7, 35049.9, 37974 0	
V47	23 0	Cepheid?	33383.8, 33593.0, 33951.9, 33959 0, 33980 9, 34035 8, 34312 0 34661 0, 34802 6, 35049 9	
V48 ..	23 0	Cepheid?	33685 8, 34442 6, 35191 7, 35870 8	Small amplitude
V49	22 9	Cepheid?	33623 0, 33650 8, 33925 0, 34779 7	Small amplitude
V50 .	22 9	Cepheid?	33681 8, 34664 0, 34719 9, 34802 6	Small amplitude
V56	19 65:	Diffuse object		See text, *V*(max) = 19 76 to 20 58
V59	22.5	Irr?		*V*(max) = 21.7

The most interesting variable of the group is V56. This object appears very diffuse on blue plates, but completely star-like on yellow plates. The estimated *B* magnitudes show considerable scatter, most, or all, of which can be explained as a photographic effect due to the image quality. However, we are convinced that the variation in *V* is real and is not caused by a spurious effect of diffuseness. The object is extremely bright, reaching $B \simeq 19.7$, $V \simeq 19.8$ at maximum: values which correspond with $M_B(\max) = -8.1$ and $M_V(\max) = -7.9$. V56 is also very blue. The enigma is that, to appear diffuse, the true image size must be at least 0.5″ in diameter which, at a true distance of $r = 3.3 \times 10^6$ pc, requires a linear diameter of 8 pc. Evidently the object cannot be an ordinary planetary nebula with a variable central star because the size is much too large (O'Dell 1962), even though the absolute luminosity is approached by at least a few central stars of such nebulae (O'Dell 1963), and central stars of planetary nebulae are known to vary (Kohoutek 1966). We do not know if the nebulosity is bright in Hα. The nature of the object remains a mystery.

XI. OTHER COMPONENTS OF THE STELLAR CONTENT

a) Brightest Stars

In late Sc and Irr galaxies of absolute integrated magnitude brighter than $M_B = -18$, the brightest resolved stars occur at about $M_B = -9.3 \pm 0.2$ (m.e.) (Sandage 1962). The calibration can eventually be improved by more precise photometry in galaxies of the Local Group and in other nearby systems. As a first step in this recalibration, we have counted stars over the face of NGC 2403, together with a nearby comparison field so as to determine the B magnitude at which appreciable numbers of stars belonging to NGC 2403 first appear.

A circular area of radius 9.′53, centered on NGC 2403, was chosen for the count of galaxy stars. The region has an area of 0.080 sq. degree and encompasses the entire visible region of the galaxy. Counts were made on two good 200-inch plates by constructing a photometric catalogue of all stars in the interval $16.50 \leq B < 19.95$. Magnitudes of 315 objects, most of which are not clusters or emission patches as judged by the crispness of the images, were estimated relative to the adopted magnitude sequence by use of a step-scale plate. A third 200-inch photograph was used to strengthen the estimated magnitudes for objects with $17.50 \leq B < 19.25$. The mean error of the adopted magnitudes is less than 0.1 mag except for stars on heavy background where the error is considerably greater. The magnitude distribution of the stars in the field of NGC 2403 is given in the first column of Table 10.

A comparison field was chosen in an annular ring centered on the galaxy whose inner radius (11.′5) was large enough to be completely removed from NGC 2403. The outer radius of the annulus was 22.′3, giving an area for the comparison field of 0.32 sq. degree. Magnitudes of all stars in this field, within the interval $16.60 < B < 19.50$, 413 in number, were estimated on a short-exposure 48-inch Schmidt plate using a step scale. The average error of an estimated magnitude is 0.1 mag.

Column (2) of Table 10 lists the comparison field star counts reduced by a factor of 4 to normalize to the same area as the galaxy field.

The difference between columns (1) and (2) is listed in column (3) and represents the excess of stars in the NGC 2403 field. Histograms of columns (1) and (3) are shown in Figures 15*a* and 15*b*. The statistical significance of the excess values of column (3) can be tested by noting that the variance in the foreground count of column (2) is the square root of the number listed therein. Inspection of Figures 15*a* and 15*b* shows that stars first appear in NGC 2403 in numbers in excess of $2.5\sqrt{n}$ of the foreground count in the interval $18.15 < B < 18.35$, thereafter dropping in the next two intervals of 0.2 mag, and rapidly rising again for $B > 18.8$. These data suggest that $B = 18.25 \pm 0.1$ is the magnitude of first occurrence of stars in NGC 2403, although from this material alone, it could be as faint as 18.8 due to our poor statistics.

However, there is strong additional support that $B = 18.25$ is correct. The six counted stars within the galaxy field in the interval $18.20 < B < 18.33$ all have quite distinctive positions relative to the galaxy, a fact which strongly suggests that they are members. The stars are close to heavy concentrations of fainter stars in the spiral arms, or to H II regions. Furthermore, two of the six have negative $(B - V)_0$ values, as determined from the blue plates and from two excellent V plates. Although none of the bright blue variables of § VII are among the six stars because they are faint on the plates which were counted, these variables do reach comparable magnitudes of $B \simeq 18.2$, and there is no question of their membership in NGC 2403. We, therefore, conclude that the brightest stars in NGC 2403 appear at $B = 18.25 + 0.1$ mag which gives M_B (brightest stars) $= -9.55$ mag if we adopt an apparent blue modulus of $(m - M)_{AB} = 27.80$ as derived in the next section.

b) Clusters

During the inspection of each image in the preceding count program we noticed four diffuse objects which have all the characteristics of clusters similar to those found by

Hubble (1932) in M31. Table 11 gives the estimated B and V magnitudes together with a description of the image appearance. A fifth very bright object at the center of a large, circular H II region was found at $V \simeq 17.0$ which is so much brighter than the brightest resolved stars that we consider it to be a group of several OB stars, such as the cluster at the center of NGC 604, the brightest H II region of M33. We originally suspected this object to be variable with $\Delta B \simeq 1$ mag, but it was later found that the estimated brightness is a clear function of the plate quality. The object seems bright on plates with lightly exposed background and faint on heavily exposed plates. This fact indicated that estimated magnitudes of objects superposed on very heavy background can be subject to large, spurious photographic effects which can only be evaluated by using comparison stars on similar background densities.

Four of the five clusters have negative color indices. They, therefore, cannot be globular clusters, but rather resemble very young galactic clusters such as NGC 457, NGC 663, and h and χ Persei, which have quite blue total colors, and integrated magnitudes between $M_B = -9$ to $M_B = -10$ (Buscombe 1963; Sandage 1963, Table 3).

TABLE 10

STAR COUNTS IN THE FIELD OF NGC 2403 AND IN A NEARBY COMPARISON AREA

B	Counts in NGC 2403 Field (1)	Normalized Comparison Field (2)	Excess (3)
16 45–16 55 . .	3	(1 5)	+(1 5)
16 55–16 65	2	3 8	− 1.8
16 65–16 75	2	4.0	− 2 0
16.75–16 85.	4	3.2	+ 0 8
16 85–16 95	3	3 2	− 0 2
16 95–17 05	3	1.5	+ 1 5
17 05–17 15	5	2 0	+ 3 0
17.15–17 25 .	1	3 0	− 2 0
17 25–17 35	3	3 8	− 0 8
17 35–17.45 .	3	3 5	− 0 5
17.45–17 55 .	3	1.5	+ 1 5
17.55–17 65	4	4 2	− 0 2
17 65–17.75	4	1 5	+ 2 5
17 75–17 85 .	1	1 0	0.0
17.85–17.95 .	3	1.2	+ 1.8
17 95–18 05	1	2 5	− 1.5
18 05–18 15	3	5 0	− 2 0
18 15–18.25	7	4 2	+ 2 8
18 25–18 35	8	3 0	+ 5.0
18 35–18 45.	4	2 8	+ 1.2
18 45–18 55	7	4 0	+ 3 0
18 55–18 65.	4	5.0	+ 1 0
18 65–18 75	4	2 5	+ 1.5
18 75–18 85 .	7	4.0	+ 3 0
18 85–18 95	14	4 5	+ 9.5
18 95–19 05	11	5 8	+ 5 2
19 05–19.15 .	12	5 2	+ 6 8
19.15–19 25.	13	2 8	+10 2
19 25–19 35. .	12	6 8	+ 5 2
19.35–19 45 .	14	7 8	+ 6.2
19.45–19 55	21	(4 8)	+(16.2)
19 55–19 65. .	22	.	
19 65–19 75. . .	30		
19.75–19 85. . .	38		
19.85–19.95. . . .	39	. . . .	. .

On the other hand, cluster C4 with $(B - V)_0 = +0.85$ and $M_B = -9.6$ could well be a globular cluster such as ω Cen or 47 Tuc which have $M_B \simeq -10.3$, $(B - V) \simeq +0.8$, and $M_B \simeq -9.9$, $(B - V) \simeq +0.9$, respectively (Gascoigne and Burr 1956; van den Bergh 1967).

c) H II *Regions*

There are at least one hundred H II regions over the face of NGC 2403 as found by Véron and Sauvayre (1965) and in an unpublished study with the 200-inch telescope

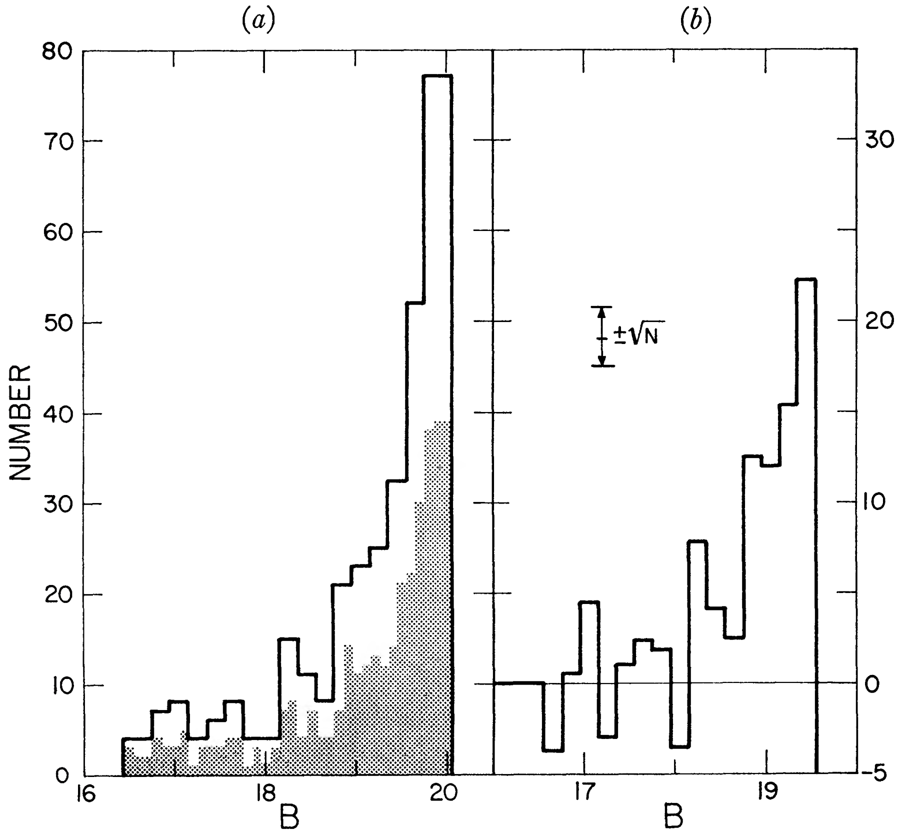

FIG. 15*a*.—Histogram of the number of stars in a circular area of 0 08 sq. degree centered on NGC 2403. The stippled region represents the counts per 0.1 mag interval. The solid outline represents counts per 0.2 mag interval.

FIG. 15*b*.—The excess of the number of stars in the field of the galaxy over that in the comparison field, plotted from the data of Table 10. The bar indicates the mean value of $\sqrt{N}$ of the number of stars in the comparison area, normalized to 0.08 sq. degree.

TABLE 11

PROPERTIES OF FIVE POSSIBLE CLUSTERS

Name	B	V	$(B-V)_0$	M_B	M_V	Remarks
C1	18 50	18 54	−0 10	− 9 3	− 9 2	Clearly diffuse: stellar core
C2	18 59	18 49	+ 04	− 9 2	− 9 2	Clearly diffuse: stellar core
C3	18 25	18 41	− 22	− 9 5	− 9 3	Clearly diffuse: stellar core
C4	18 22	17 31	+ 85	− 9 6	−10 4	Very dense; image diffuse
C5 .	17 0:	17 25:	−0 25:	−10 8:	−10 5:	Stellar image; in center of H II

using an 80 Å half-width Hα interference filter (Sandage 1962). The angular sizes and distribution across the galaxy will be discussed elsewhere, and we only note here that the angular diameters of the largest and the mean of the first five largest regions are 15″.6 and 11″.5, respectively (Sandage 1962), values which we have rechecked in the present investigation. These disagree with values given by Véron and Suavayre, but it should be pointed out that the scale of the plates used by these authors is exceedingly small, and that the data from the 200-inch plates are to be preferred.

d) Novae

No novae have been found in NGC 2403. After very detailed re-examination of the discovery plate, the nova reported by Ritchey (1917) proved to be a dust grain. By use of typical parameters of the light-curves for novae, and making allowance for time coverage of our plates and their different quality, we estimate the upper limit for novae in NGC 2403 to be <1 nova/year as compared to 26 novae/year in M31 (Arp 1956). This is in agreement with Hubble's result (Bowen 1954) that the occurrence of novae seems to be very unlikely in Sc galaxies (M33, NGC 2403) as compared with Sb galaxies (M31, M81).

XII. DISTANCE TO NGC 2403

The following distance indicators have been used: (1) the Cepheid variables in B and V light; (2) the brightest of the blue irregular variables; (3) the brightest resolved stars, presumed to be A and F supergiants; (4) the brightest red irregular variables; and (5) the angular sizes of the first ranked, and the mean of the first five largest of H II regions. The calibration of some of these indicators via galaxies in the Local Group has been partially discussed in the previous sections.

a) Cepheids

The period-luminosity relation defined by the seventeen stars of Table 5 shows considerable scatter in B(max), but surprisingly is much more concise in V(max), even though the light-curves in V wavelengths are more sparsely defined. The first thought that much of the scatter is caused by variable internal absorption is not correct if the normal ratio of absorption to reddening applies. This follows because the correlation between the magnitude residuals R_B and R_V and the color residuals $\delta(B - V)$ listed in Table 5 have very much smaller slopes than 4 and 3, respectively. These correlations, which the reader can plot from Table 5, are remarkably good considering the great difficulty of the color determination. The slopes of the relations are $\Delta R_B/\Delta\delta(B - V) = 1.60$ and $\Delta R_V/\Delta\delta(B - V) = 0.73$, which differ significantly from the reddening values. However, they also differ somewhat from similar relations derived for galaxies in the Local Group (Sandage and Tammann 1968, Fig. 7), correlations which have slope coefficients of 2.6 and 1.7, respectively. Although we have no explanation for this difference, we are convinced that the scatter in the B(max)–P relation is not primarily caused by local obscuration, because if this were so, the spread in $\delta(B - V)$, ranging from -0.2 to $+0.7$, should cause an observed spread of 3.6 mag in B(max), whereas the observed scatter is only $\Delta B(\max) = 1.6$ mag. We therefore conclude that much of the scatter is intrinsic and due to the causes discussed elsewhere (Sandage and Tammann 1968). These causes also explain why the scatter in the V(max)–P relation is smaller than that in the B(max)–P function.

The one remaining problem in the present data concerns the observed colors of about half the Cepheids at maximum light. These colors, assumed now to be nearly intrinsic values because of our assumption of nearly negligible internal absorption, average about 0.4 mag redder than the normal colors of galactic Cepheids (Sandage and Tammann 1968, Fig. 7), and this is part of the same problem for which we have no explanation.

The distance to NGC 2403 can now be determined from the Cepheids by comparing our observed *P-L* relation with that previously derived at maximum light from Cepheids in the Local Group, calibrated with the nine Cepheids in galactic Cepheids and associations (Sandage and Tammann 1968; Fig. 5; Table A1). Because the sample of Cepheids at a given period must be incomplete in NGC 2403 due to our working so close to the plate limit, we assume that the brightest observed Cepheids fall on the upper envelope of the standard relation. This assumption has the added advantage that if there is local absorption for some of the Cepheids, as must be the case for at least V54, the upper envelope line, defined by the brightest and bluest of the stars, is unaffected. Justification for this view is available from the fact that the six brightest Cepheids with $\log P \geq 1.481$ have observed colors which lie within the intrinsic scatter of the calibrated period-color relation given elsewhere (Sandage and Tammann 1968, Fig. 6).

The upper envelope of the plotted data from Table 5, compared with the upper envelope of the standard *P-L* relation at maximum light gives apparent blue and visual distance moduli of $(m - M)_{AB} = 27.80 \pm 0.1$ and $(m - M)_{AV} = 27.75 + 0.1$. Assuming absorptions due to the galactic system of $A_B = 0.24$ and $A_V = 0.18$ gives true moduli of $(m - M)_{0,B} = 27.56$ and $(m - M)_{0,V} = 27.57$ for NGC 2403 from the Cepheids alone. The agreement between the blue and visual data are, of course, better than the errors involved and should be considered fortuitous. A realistic estimate of the error is perhaps ± 0.2 mag in each color.

b) Brightest Blue Irregular Variable

V38 reaches $B(\max) = 18.2$. If we use as calibration only the brightest variable in M33 (star B) at $M_B(\max) = -9.5$ and the brightest in M31 (V19) at $M_B = -9.1$ for a mean of $-9.3 + 0.2$, then $(m - M)_{AB} = 27.5 \pm 0.2$ or $(m - M)_{0,B} = 27.3 \pm 0.2$ for NGC 2403. The determination obviously has small weight due to the size of the sample. Agreement with the Cepheid modulus can be obtained if we adopt $M_B(\max) = -9.60$ for the brightest blue variable.

c) Brightest Resolved Stars

The star counts discussed in § XI show that the blue stars begin to appear in NGC 2403 at $B = 18.25 \pm 0.1$ mag. The calibration suggested previously (Sandage 1962) gave M_B(brightest star) $= -9.3 \pm 0.2$, but among these stars are the bright blue variables in M31 and M33. Therefore, this method is only partially independent of method *b*. Adopting M_B(brightest star) $= -9.3$ gives $(m - M)_{AB} = 27.55 \pm 0.3$ or $(m - M)_{0,B} = 27.3 \pm 0.3$ for NGC 2403.

d) Brightest Red Irregular Variables

As shown in § VIII, the brightest red variable in *V* and *B* gives distance moduli for NGC 2403 of $(m - M)_{A,V} = 27.98 \pm 0.1$, $(m - M)_{0,V} = 27.80 \pm 0.1$ and $(m - M)_{A,B} = 28.02 \pm 0.2$, $(m - M)_{0,B} = 27.78 \pm 0.2$, when the calibration of absolute magnitudes of corresponding variables in the LMC, SMC, and NGC 6822 are used. As mentioned previously, the calibration can be improved by a more complete sampling of the Magellanic Clouds and by a study of the red variables in M33. Furthermore, the upper envelope of the red supergiant population can eventually be used rather than the bright red variables.

e) Sizes of H II *Regions*

Preliminary calibration (Sandage 1962) suggests that the largest, and the mean of the first five largest H II regions in late Sc and Irr galaxies have linear diameters of 245 ± 20pc and 178 ± 33 pc, respectively, based only on M33 and the LMC. The calibration can soon be greatly improved with NGC 6822, IC 1613, and all members of the M81 group using the results of this paper. Adopting these calibrations for the moment, and using angular diameters in NGC 2403 of 15′.6 and 11′.5 for the largest and the first five largest give $(m - M)_{0,L} = 27.54 \pm 0.18$, and $(m - M)_{0,5} = 27.52 \pm 0.40$ which are almost identical to the Cepheid values.

f) Summary

The individual results of all the methods are summarized in Table 12. The agreement of the methods is excellent, which shows that there is strong evidence that the distance indicators calibrated within the Local Group, relative to the Cepheids in each galaxy, show no systematic deviation greater than about ± 0.2 mag (which is the accuracy of each method) among themselves when taken in this single step to NGC 2403 beyond the Local Group.

Although the final mean modulus of $(m - M)_0 = 27.55 \pm 0.13$ (A.D.) is almost identical to the Cepheid value alone, a realistic estimate of the errors again shows this to be fortuitous. Adopting the Cepheid modulus of $(m - M)_{0,V} = 27.56$, we can now

TABLE 12

SUMMARY OF INDIVIDUAL MODULI FOR NGC 2403

Method	$(m-M)_0$
Cepheids (*B*)	27.56±0 1
Cepheids (*V*)	27 57± .1
Brightest blue variable	27.3 ± .2
Brightest resolved stars	27.3 ± .3
Brightest red irreg. (*B*)	27 78± .2
Brightest red irreg. (*V*)	27.80± .2
H II region (*L*)	27 54± .18
H II region (5)	27.52± .40
Mean	27.55±0 13 (A.D.)

turn the problem around and can calibrate the individual indicators in NGC 2403, and indeed, all members of the M81 group to obtain better statistics. Such a discussion will be given in future papers, when photometry of NGC 2366, M81, IC 2574, Ho II, and NGC 4236, is complete.

Besides the distance modulus, we believe the most interesting result to come from this study is the possibility that red supergiants are good distance indicators. Not only are these easy to discover, but they are unique and occur singly, rather than in clusters or in multiple aggregates as for the O, B, and A supergiants. Furthermore, they are so red that confusion with nearby galactic foreground stars is largely avoided, which is not the case for stars bluer than $B - V = 1.9$, as seen from Becker's (1967) results in SA 51 at $b^{II} = +21°$ where large numbers of stars bluer than $B - V = +1.9$ were found to $V \simeq 21.2$ mag, but no redder objects were present. The result is also consistent with the Greenwich proper-motion study in the field of the LMC (Woolley 1963), which shows that confusion between local and extragalactic stars dominates the statistics in the range $0.5 < B - V < 1.5$.

Figure 12 suggests that an upper envelope exists for the reddest stars in NGC 2403 at about $V = 20.0$, which, with $(m - M)_{AV} = 27.74$, gives $M_V = -7.7$ as determined from this galaxy alone. Use of this indicator in M101 will be discussed in a future paper.

As a final remark, we found it amusing to apply the distance of $(3.25 \pm 0.20) \times 10^6$ pc for NGC 2403 to the remainder of the M81 group, and to combine this value with the mean redshift of the group determined from nine of its members. Individual redshifts are known for M81, M82, NGC 2403, IC 2574, Ho II, NGC 2366, NGC 2976, NGC 3077, and NGC 4236 (Humason, Mayall, and Sandage 1956; Epstein 1964, neglecting his value of M82), each corrected for a solar motion of 300 sin l^{II} cos b^{II}. These data are used to obtain the ratio of redshift to distance. The mean corrected redshift for the group is 210 ± 33 km/sec, giving

$$\frac{v}{r} = 65^{+15}_{-14} \text{ km/sec Mpc}.$$

Although we do not claim that this value bears any relation to the Hubble constant because: (1) the result is so sensitive to the correction for solar motion; (2) no cognizance is taken of possible non-isotropic effects in the velocity field (de Vaucouleurs 1958, 1966); and (3) the back-to-front ratio of $dr/r = 0.24$ for the M81 group of radius 14° (Holmberg 1950) is neglected, it is interesting that the value is close to the range in which the Hubble constant is believed to lie. The current plan for the redetermination of H is to apply some of the calibrators discussed in this paper to many galaxies in the nearby field so as eventually to determine the regression of v on r, using an adequate statistical sample.

One of us (G. A. T.) wants to express his deep gratitude to Drs. I. S. Bowen and H. W. Babcock, and to the staff members of the Mount Wilson and Palomar Observatories for their hospitality and their continuous encouragement. He is also indebted to the Swiss Holderbank Foundation for a travel grant.

We both are grateful to many members of the nebular department, especially Dr. M. L. Humason, who obtained a number of plates at the beginning of the program.

APPENDIX

Table A1 lists individual B magnitudes and phases for the seventeen Cepheids in Table 5 of the text. Estimates on an uncalibrated Argelander scale, relative to faint sequence stars a, b, and c, are given when the star is fainter than the calibrated stars of Table 2. It is always the case that when three arbitrary stars are used, c is the same as the faintest calibrated star of the sequence. When only two fainter stars are used, b is identical with the faintest calibrated star of Table 2. The symbol "(" means "fainter than." The symbols F and B mean "faint" and "bright" and are used only on poor-quality plates where magnitude values are uncertain, but where estimates are important for the period determination.

Table A2 lists similar data for V magnitudes of the Cepheids.

Table A3 lists B magnitudes for the eight blue irregular variables of Table 6, and for the eclipsing binary V55 with phases computed with a period of $6^{d}06702$.

Table A4 gives V magnitudes for the blue irregular variables, together with magnitudes for all of the red supergiant irregulars of Table 7, except for V58, which is so faint as to be invisible on most plates. No B magnitudes are tabulated for the red stars, although the data for B(max) are listed in Table 7 of the text.

TABLE A1

B MAGNITUDES AND PHASES FOR 17 CEPHEIDS

Plate	Date	J D⊙ 2430000+	Exp. Time (min)	Qual.	V 1 *B*	V 1 Phase	V 3 *B*	V 3 Phase	V 4 *B*	V 4 Phase	V 5 *B*	V 5 Phase	V 6 *B*	V 6 Phase	V 8 *B*	V 8 Phase
PH- 5-H	1949 Jan 27/28	2944 8	30	VP	(a4	0 690	F	0 848	22 46	0 996	22 07:	0 016	F	0 524	(a	0 706
19-H	Feb 18/19	2966 732	45	P	a	247	..	099	F	566	a	488	b:	248	F	344
30-H	Feb 21/22	2969 710	45	P	a4	323	B	133	F	644	a4	552	(b	347	(a	431
39-H..	Feb 25/26	2973 664	45	P	(a	423	22 0 :	178	(b	747	(b7a	637	F	477	b8a:	546
36-MH	1950 Jan 15/16	3297 8	35	FG	a8	656	22.61	884	(a	209	a4	614	c5b	189	b4a	981
120-MH	Mar 20/21	3361 8	30	G	a8	281	b1a	615	22.53	880	21 76	991	a4	304	(a	844
139-MH	Apr 11/12	3383 8	30	FG	a4	840	23.03	867	b5a	454	a4	465	22 80	031	a	484
148-MH	Apr 12/13	3384 8	30	F	a4	865	c5b	878	22 6 :	480	(a	486	22.41	064	b5a	513
71-H	Oct 13/14	3569 024	26	FG	a8	544	21 92	984	(a	310	a4	451	c3b	152	a4	876
318-B	Oct 17/18	3573 027	29	G	a8	646	22 04	030	(b5a	394	a4	537	a	284	22.09	993
344-B	Nov 6/7	3592 989	30	VG	b2 5a	153	22 26	258	22 24	915	22 07	967	22.32	944	b7a	574
85-H	Nov 11/12	3597 964	30	FP	(a	279	23 10	315	22 46	045	22 27	074	c5b	108	a	718
98-H.	Dec 6/7	3622 977	30	F	22 36	914	(a	601	(b	698	a	613	22 80	935	a2	446
114-M.	Dec 8/9	3624 944	30	F	21 99	964	a	624	(b	749	a	655	22 12	000	a	504
250-MH	Dec 15/16	3631 8	25	P	B	138	22 96	702	22.53:	928	F	803	F	227	F	703
254-MH	1951 Jan 3/4	3650 8	30	FG	a8	631	22 12	919	c5b	424	22.39	211	a4	855	b4a	256
256-MH	Jan 7/8	3654 8	30	FG	(a4	723	22 12	965	(b	529	b7a	298	22 32	987	b5a	373
124-M.	Jan 13/14	3660 8	30	F	(a4	875	22 68	033	F	685	(a	427	b	185	F	548
263-MH	Feb 2/3	3680 8	30	P	(a	383	22 96	262	F	207	F	857	F	846	B	130
268-MH	Feb 3/4	3681 8	30	FG	a8	408	22 54	273	c5b	234	a	879	(a	879	22 44	159
274-MH	Feb 7/8	3685 8	30	F	a4	510	22 56	319	F	338	22 27	.965	22 12	011	22 85	275
289-MH	Mar 3/4	3709 8	30	P	b3a	119	..	594	22 38	965	F	481	F	804	22 3 :	974
358-B..	Mar 8/9	3714 675	30	FG	b5a	241	F	648	.	089	a4	584	22 12	962	22.16	116
291-MH	Apr 1/2	3738 8	30	P	(a4	856	22 26	925	(a	721	22 39	106	F	763	(b5a	818
546-B	Oct 4/5	3925 010	30	G	a8	585	21 97	054	b	583	22 27	114	22.32	916	b5a	234
554-B	Oct 31/Nov 1	3951 951	30	G	a8	269	23 10	362	b	286	a4	693	a4	807	22 02	023
23-S	Nov 5/6	3956 937	25	P	(a	396	b	419	(b	416	a4	801	22 32	871	22.9 :	168
35-S	Nov 7/8	3958 968	25	G	a8	448	c4b	442	(b7a	469	a2	844	22 32	039	b2a	227
44-S	Nov 8/9	3959 969	30	F	b5a:	473	22.61	453	(b	495	a4	866	22 80:	072	b4a	256
47-S	Nov 29/30	3980 859	30	G	21 99	004	b7a	692	22 7 :	041	22.50	316	a4	762	a4	864
62-S	Dec 2/3	3983 893	30	FG	22 36	081	b9a	727	22 75:	120	b5a	381	(a	862	b6a	952
78-S	Dec 26/27	4007 901	30	FG	(a4	690	21 91	001	b	747	b7a	898	a4	656	a4	651
92-S	1952 Jan 3/4	4015 891	30	FG	b5a	893	22 12	093	22 38	955	22 27	070	22 41	920	(a	884
100-S..	Jan 23/24	4035 813	30	FG	(a	399	22 68	320	(a	475	a2	498	(a	578	b4a	464
3-Bm	Jan 30/31	4042 820	30	G	a8	577	22.68	400	a	658	a2	649	a4	810	b9a	668
391-MH	Feb 15/16	4058 695	30	G	22 04	980	c4b	582	22 53	073	21 87	991	a4	334	22 44	130
401-MH	Feb 24/25	4067 679	30	P	F	209	(a	685	F	307	22 28	184	F	631		391
408-MH	Mar 24/25	4096 671	30	VP	.. ..	945	.. ..	016	.. ..	064	.	808	..	589	...	235
412-MH	Mar 25/26	4097 659	30	FG	22 16	970	22 61	027	22.38	090	a	830	(a	622	b2a	264
420-MH	Apr 15/16	4118 672	30	FG	a8	504	22 54	268	(b5a	638	b7a	282	b5a	316	b9a	876
434-MH	Apr 22/23	4125 684	30	FG	a8	682	22 68	348	(b	821	(a	433	(a	548	22.23	080
158-H	Oct 14/15	4300 985	30	VG	a	134	22.26	352	b	398	22.33	206	b5a	341	b5a	183
180-S	Oct 25/26	4311 989	30	G	a8	414	c6b	477	(b5a	685	b5a	443	(a	705	b7a	503
193-S	Oct 26/27	4312 963	30	P	..	438	.	489	.. ..	710	..	464	...	737	.. ..	531
209-S	Nov 10/11	4327 934	30	FG	a8	819	(a	660	22 31	101	a4	786	c5b	232	22 72	967
231-S	Nov 24/25	4341 883	30	P	B	173	F	819	F	463	22 33	086	F	693	22 6 :	373
255-S	Dec 9/10	4356 923	25	F	F	555	22 04	991	c8b:	858	(a	410	c3b:	190	a2	811
264-S	Dec 10/11	4357 910	30	F	F	580	21 90	002	b:	884	b3a	431	c:	222	(a	839
290-S	Dec 22/23	4369 851	30	F	22 4 :	.883	22 68	139	22.9 :	195	a	688	(b3a	616	22 44	187
309-S	1953 Jan 8/9	4386 764	30	FG	a	:313	22 82	332	(b5a	637	21 87	052	c	176	(a	679
331-S	Jan 16/17	4394 714	30	FG	(a4	515	23 10	423	(a	845	22 50	223	c5b	439	a2	911
359-S	Feb 6/7	4415 718	30	P	22.4 :	048	(a	663	b:	393	a4	675	F	133	F	522
375-S	Feb 17/18	4426 761	30	FG	b5a	328	F	789	b5a	681	22.50	913	(a	498	b6a	844
393-S	Mar 5/6	4442 649	30	F	(a4	732	22 75	971	.. .	096	b5a	255	22 51	023	22 8 :	306
409-S	Mar 6/7	4443 661	30	G	b5a	758	21 97	983	22 9 :	122	b5a	277	22 80	056	a	336
467-S	Mar 17/18	4454.646	30	FG	22 29	037	22 19	108	b:	409	a2	513	a4	419	(a	655
468-S	Mar 17/18	4454 676	10	F	22 36	037	22 12	109	b	410	a2	514	(b	420	a4	656
598-S	Oct 9/10	4660 979	44	G	a8	277	b	467	b:	796	22 07	954	b	238	(a	662
629-S	Oct 12/13	4663 990	25	G	a8	354	22 89	501	22.90	874	21 45	019	b5a	337	(a	749
891-B	Dec 5/6	4717 836	30	G	a8	721	21 97	117	(b5a	280	22 50	178	d3c	117	b6a	317
901-B	Dec 6/7	4718 848	30	G	a8	747	22 26	128	(a	306	22 44	200	c3b	150	a2	346
641-S	Dec 7/8	4719 902	30	G	(a4	774	22.47	141	c7b	334	22 44	223	d5c	185	b4a	377
649-S	1954 Feb 4/5	4778 681	30	FG	b5a	266	b7a	812	22 75	868	a2	488	d5c	127	22 31	088
661-S	Feb 5/6	4779 688	30	FG	b2 5a	292	c1b	824	22 75	895	(a	509	d5c	161	22 58	117
671-S	Feb 6/7	4780 680	30	F	a	317	23 10	835	22 5 :	920	(a	531	c5b	194	22 85	146
672-S	Feb 7/8	4781 779	30	F	(a4	345	22 96	848	22 75	949	(a	554	c5b	230	22 85	178
678-S	Feb 8/9	4782 843	30	VP	..	372	F	860	.. ..	977	..	577	.	265	...	209
683-S	Feb 9/10	4783 876	30	F	(a4	398	22 68	872	22 38	004	a2	600	(a	299	b7a	239
693-S	Feb 27/28	4801 774	30	VP	..	853	22 3 :	076	.	471	21 66	985	F	891	..	760
700-S	Feb 28/Mar 1	4802 644	30	VG	a8	875	22 12	086	b	494	21 66	004	22 75	919	a4	785
851-S	Nov 2/3	5049 946	20	FG	a	156	22 75	913		950	(a	326	b	092	22 16	984
893-S	1955 Jan 23/24	5131 726	21	P	..	233	...	848	.	085	22.27:	087	..	795	.. ..	364
900-S	Mar 24/25	5191 691	30	VG	a8	756	c9b	534	(a	650	b5a	377	a4	776	22.16	110
1122-S	Oct 20/21	5401 963	30	FP	22.30	096	22 96:	938	...	139	(a	903	(a	725	b1a:	231
1143-S	Oct 23/24	5404 976	25	FG	b5a	173	22 33	972	(c7b	218	21 97	968	a	825	b2a:	318
1167-S	Dec 14/15	5456 905	30	VG	a4	492	(a	566	(a	574	22 28	086	a4	404	(a2	830
1338-S	1957 Jan 31/Feb 1	5870 836	25	F	22.04	005	23 03	297	(b	380	21 45	995	b	220	F	879
1355-S	Feb 4/5	5874 757	25	VG	b3a	104	22 61	342	(a	482	22 27	080	b5a	349	22 09	993
1358-S	Feb 4/5	5874 828	25	VG	22 36	106	22 47	343	(b5a	484	21 97	081	a	352	22 02	995
32-A	1958 Jan 15/16	6219 780	30	P	..	867	..	286		489	F	506		751	22 0 :	036
3216-A	1959 Mar 3/4	6631 766	25	VP	F	331	B	996	.. ..	244	22 28	373		366	B	029
3584-S	1960 Apr 18/19	7043 707	25	FG	(a4	793	b5a	705	22 60:	998	22 50	240	. .	980	22.16	020
3721-S	Nov 23/24	7263 013	25	G	b7a	363	22 61	212	(a	723	22 07	960	(a	227	b9a	404
3735-A	Dec 22/23	7292 780	165	P	22 1 :	119	...	552	b:	500	.. ..	601	.	211	.. ..	272
4054-S	1962 Nov 4/5	7974 028	35	G	a8	431	c7b	340	b5a	285	22 39	264	a	724	22 16	101
4196-S	1963 Mar 18/19	8107 723	35	F	a8	816	22 19	868	(b	775	22 27	142	c5b	142	22 16	992
4199-S	Mar 19/20	8108 648	35	P	.	840	B	879	..	749	B	162	...	173		019
PH-4213-S	Mar 20/21	8109 651	35	FP	(a	0 865	22 68	0 890	F	0 825	b3a	0 183	c5b	0 206		0 048

TABLE A1 -continued

Plate	Date	J D ⊙ 2430000+	Exp. Time (min)	Qual.	V 15		V 19		V 21		V 25		V 29		V 33	
					B	Phase	*B*	Phase	*B*	Phase	*B*	Phase	*B*	Phase	*B*	Phase
PH- 5-H	1949 Jan 27/28	2944 8	30	VP	B	0 030	.	0 241	B	0 045		0 439	22 8 :	0 407	.. .	0 626
19-H	Feb 18/19	2966 732	45	P	..	684	(b	510	(22.75	600	..	905	21 42	072	22 6 :	.015
30-H	Feb 21/22	2969 710	45	P	F	772	b5a	546	(b5a	676	B	968	21.65	162	22 6 :	068
39-H..	Feb 25/26	2973 664	45	P	22.48	890	b3a	595	.. ..	088	21 42:	052	(b5a	282	22 65:	139
36-MH	1950 Jan 15/16	3297 8	35	FG	b3a	549	b	572	22 64	981	21 51	932	21 65	106	22 74	902
120-MH	Mar 20/21	3361 8	30	G	b5a	456	22.66	358	a2	601	21 89	291	21 60	046	22 56	039
139-MH	Apr 11/12	3383 8	30	FG	22 41	112	b5a	628	b5a	127	(a4	758	a4	713	22 79	431
148-MH.	Apr 12/13	3384 8	30	F	22.41	142	(a	641	b2a	187	a4	779	a	743	22 79	448
71-H	Oct 13/14	3569 024	26	FG	(b5a	631	22 50	900	(a	846	(a4	690	22 80	327	a	724
318-B	Oct 17/18	3573 027	29	G	b3a	751	22 09	950	22 81	947	a8	775	a	448	22 79	795
344-B	Nov 6/7	3592 989	30	VG	22.85	345	22 23	195	(a	452	21 60	198	21 60	053	22 58	150
85-H	Nov 11/12	3597 964	30	FP	b5a	494	22.80	256	(a	578	22 09	304	21 69	204	22.46	238
98-H.	Dec 6/7	3622 977	30	F	22 41	239	b7a	563	b6a	212	a8	835	21 60	962	b8a	683
114-M.	Dec 8/9	3624 944	30	F	b	298	a4	587	(a	261	(a4	877	21 51	022	a4	718
250-MH	Dec 15/16	3631 8	25	P	.. ..	502	a:	671	.. ..	435	21 32:	022	22 80	230	.. ...	840
254-MH	1951 Jan 3/4	3650 8	30	FG	22 44	068	22 21	904	22 72	916	22 09	426	a4	806	22 46	178
256-MH	Jan 7/8	3654 8	30	FG	22.41	187	22 36	953	22 64	017	a4	510	22 20	927	22 56	249
124-M.	Jan 13/14	3660 8	30	F	c5b	366	21.95	027	a	169	(a4	638	21.65	109	22 61	355
263-MH	Feb 2/3	3680 8	30	P	.. ..	962	c5b:	272	(a	675	21 84:	062	(b3a	715	...	711
268-MH	Feb 3/4	3681 8	30	FG	22 15	992	22 50	284	a	701	21 37	084	a4	745	b7a	729
274-MH	Feb 7/8	3685 8	30	F	22 25	111	22 54	333	22 85	802	21 69	168	(a	867	b6a	800
289-MH	Mar 3/4	3709 8	30	P	b	824	(a	628	..	409	..	678	(a	594	22 58:	227
358-B..	Mar 8/9	3714 675	30	FG	22 15	972	a	687	F	533	(a4	759	(a	739	22 67	313
291-MH	Apr 1/2	3738 8	30	P	.. ..	691	22 18	984	F	143	21 94	294	(b5a	473	.. ..	742
546-B	Oct 4/5	3925 010	30	G	22 48	239	22.40	269	22 75	857	21 94	246	21 69	117	22.37	053
554-B	Oct 31/Nov 1	3951 951	30	G	21 92	042	a	599	a	539	a8	818	21 65	934	b8a	532
23-S	Nov 5/6	3956 937	25	P	22 41	191	(a	661	a2	665	21 60	924	21.60	085	(a	620
35-S	Nov 7/8	3958 968	25	G	22 76	251	a	685	(a	716	21 26	967	22 30	146	a4	656
44-S	Nov 8/9	3959 969	30	F	22 85	281	(a	698	(b5a	742	21 32	988	22 25	177	(a	674
47-S	Nov 29/30	3980 859	30	G	22 44	904	21 95	954	a	270	22 09	432	a4	810	22 37	046
62-S	Dec 2/3	3983 893	30	FG	22 15	994	21 81	991	b8a	347	a4	496	22 47	902	22.37	100
78-S	Dec 26/27	4007 901	30	FG	b	709	22 37	286	22.75	955	21 19	006	a4	629	b9a	526
92-S	1952 Jan 3/4	4015 891	30	FG	22.38	947	b	384	b5a	157	21 55	125	b7a	872	b9a	668
100-S..	Jan 23/24	4035 813	30	FG	b3a	541	(a	628	a4	661	(a4	598	a	475	22 17	023
3-Bm	Jan 30/31	4042 820	30	G	b3a	750	a4	714	22 87	839	a8	747	a4	688	22 46	147
391-MH	Feb 15/16	4058 695	30	G	22.76	223	22 52	909	a2	241	21 42	084	22.25	169	22 89	429
401-MH	Feb 24/25	4067 679	30	P	b2a	491	22 09	019	(a	468		275	b3a	441		589
408-MH	Mar 24/25	4096 671	30	VP	.. ..	355	...	375	.. ..	202	.. ..	890	...	320	.. ..	105
412-MH	Mar 25/26	4097 659	30	FG	22 66	384	c4b	387	23 00	227	21 74	911	b3a	350	22.46	122
420-MH	Apr 15/16	4118 672	30	FG	21 95	010	a4	645	a4	759	22 04	357	21 42	987	b7a	496
434-MH	Apr 22/23	4125 684	30	FG	22.48	219	(a	731	22 75	936	a4	506	22.25	200	a4	621
158-H •	Oct 14/15	4300 985	30	VG	c8b	443	22 49	882	a4	374	21 75	227	b5a	513	b9a	737
180-S	Oct 25/26	4311 989	30	G	b:	371	21.95	017	(a2	652	22 09	461	b5a	846	22 46	933
193-S	Oct 26/27	4312 963	30	P	.. ..	.800	VB	029	.. ..	677	..	481	...	876	22 4 :	950
209-S	Nov 10/11	4327 934	30	FG	22 66	246	22 34	213	22 78	056	a8	799	b5a	330	22 72	216
231-S	Nov 24/25	4341 883	30	P	.. ..	662	22 7 :	384	a1	409	.. ..	095	F	752	22.84:	464
255-S.	Dec 9/10	4356 923	25	F	22 66	110	(a	569	22 87	790	21 94	414	b5a	208	b7a	732
264-S	Dec 10/11	4357 910	30	F	22 44	139	(a	575	22.87	814	a4	435	22 20	238	.. ..	749
290-S	Dec 22/23	4369 851	30	F	22 85	495	a4	727	(b6a	117	a8	689	a	600	22 56	962
309-S	1953 Jan 8/9	4386 764	30	FG	22 15	999	22 09	935	a2	545	21 51	048	21 60	113	22 61	262
331-S	Jan 16/17	4394 714	30	FG	22 44	236	21 95	032	(a	746	21 64	217	22 80	354	22.72	404
359-S	Feb 6/7	4415 718	30	P	22 9 :	862	.. ..	290	(a	278	.. ..	662	21 42	990	b6a	.777
375-S	Feb 17/18	4426 761	30	FG	22 25	191	22 52	426	(a	557	21 69	897	22 52	325	22 17	.973
393-S	Mar 5/6	4442 649	30	F	...	664	(a	621	22 75	960	21 84	234	a	807	22 61	256
409-S	Mar 6/7	4443 661	30	G	b3a	695	a4	633	...	985	21 89	256	a4	837	22 61	274
467-S	Mar 17/18	4454 646	30	FG	22 05	022	a4	768	b9a	263	a4	489	21 97	170	22.89	469
468-S	Mar 17/18	4454 676	10	F	21 92	023	(a	768	a	264	a4	489	21.97	171	b7a	470
598-S	Oct 9/10	4460 979	44	G	22 66	171	22 49	300	a1	486	a8	869	b5a	424	22 61	138
629-S	Oct 12/13	4663 990	25	G	22 85	260	22 55	337	(a	562	21 42	933	(a	516	22 63	191
891-B	Dec 5/6	4717 836	30	G	22.85	865	22 09	998	22 73	925	21 37	075	22 20	147	22 65	148
901-B	Dec 6/7	4718 848	30	G	c5b	895	21 95	010	22 83	951	21 51	077	21 92	178	22 63	166
641-S	Dec 7/8	4719 902	30	G	22.48	926	21 95	023	22 69	977	21 55	119	21 97	210	22 61	.185
649-S	1954 Feb 4/5	4778 681	30	FG	b5a	678	a	744	a2	465	a4	367	21 42	992	22 58	.230
661-S	Feb 5/6	4779 688	30	FG	b5a	708	a4	757	a3	491	22 09	388	21 37	022	22 65	.248
671-S	Feb 6/7	4780 680	30	F	(b5a	737	b	769	a2	516	a4	409	21 65	052	22 67	266
672-S	Feb 7/8	4781 779	30	F	(b5a	770	c8b	782	a2	544	(a4	433	21 60	086	22 72	285
678-S	Feb 8/9	4782 843	30	VP	.	802	...	795	(b5a	571	..	455	21 60	118	22 7 :	304
683-S	Feb 9/10	4783 876	30	F	b	833	b5a	808	(a	597	a4	457	22 02	144	22 65	322
693-S •	Feb 27/28	4801 774	30	VP	F	366	22 09	028	.. ..	050	.. ..	857	22 80	692	..	641
700-S •	Feb 28/Mar 1	4802 644	30	VG	c7b	392	21 95	038	22 75	072	22 09	876	a	718	a4	656
851-S	Nov 2/3	5049 946	20	FG		761	21 95	073	(a2	332	21 55	125	22 25	214	2? 56	053
893-S	1955 Jan 23/24	5131 726	21	P	.. ..	198	.	076	.. ..	402	.. ..	861	F	692	.	507
900-S.	Mar 24/25	5191 691	30	VG	21 92	985	b	812	22 77	920	21 47	134	22.80	510	a	573
1122-S	Oct 20/21	5401 963	30	FP	22 85	251	22.52	392	a	242	(a4	597	b5a	883	22.93	311
1143-S.	Oct 23/24	5404 976	25	FG	b	341	b5a	429	(a	318	a8	661	21.51	975	b6a	365
1167-S.	Dec 14/15	5456 905	30	VG	b	888	21 95	067	a	633	a8	764	b5a	549	22 72	288
1338-S	1957 Jan 31/Feb 1	5870 836	25	F	22.15	223	22 12	146	b5a	110	a8	550	21 97	095	a2	648
1355-S	Feb 4/5	5874 757	25	VG	c3b	340	22 26	.194	a2	210	a8	633	22 25	.214	b6a	717
1358-S	Feb 4/5	5874 828	25	VG	c5b	342	22 20	195	a	211	(a4	635	22 25	216	b6a	718
32-A	1958 Jan 15/16	6219 780	30	P	.	628	F	428		943	B	957	F	671	22 74	851
3216-A	1959 Mar 3/4	6631 766	25	VP	.. ..	905	F	483	.. ..	372	.. ..	702	22 25	159	.. ..	176
3584-S	1960 Apr 18/19	7043 707	25	FG	22 41	173	a4	538	22 93	799	22 09	447	a4	645	22.72	500
3721-S	Nov 23/24	7263 013	25	G	b	708	22 49	229	a3	350	21 47	102	22 25	292	b6a	399
3735-A	Dec 22/23	7292 780	165	P	...	603	.. ..	595	..	103	.. ..	734	..	194	.. ..	928
4054-S •	1962 Nov 4/5	7974 028	35	G	(b5a	896	21.98	954	a3	348	21 60	195	a4	843	22 37	040
4196-S	1963 Mar 18/19	8107 723	35	F	b	880	b2a	595	b5a	732	21 32	033	(a	895	22.89	417
4199-S	Mar 19/20	8108 648	35	P	..	908	...	606	...	755	.. ..	052	.. ..	923	.. ..	434
PH-4213-S	Mar 20/21	8109 651	35	FP	b:	937	(b7a	619	(b5a	781	21 42	054	22 52	953	22 93:	451

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TABLE A1 -continued

Plate	Date	J D ⊙ 2430000+	Exp. Time (min)	Qual.	V 34 B	V 34 Phase	V 40 B	V 40 Phase	V 42 B	V 42 Phase	V 46 B	V 46 Phase	V 54 B	V 54 Phase
PH- 5-H	1949 Jan 27/28	2944 8	30	VP	F	0 249	..	0 643		0 621		0 189	..	0 490
19-H	Feb 18/19	2966 732	45	P	F	830	F	695		705	..	566	B	956
30-H	Feb 21/22	2969 710	45	P		909	..	838		853	F	617	F	019
39-H..	Feb 25/26	2973 664	45	P	.	014	B	028	.. ..	048	F	685	22 98:	104
36-MH	1950 Jan 15/16	3297 8	35	FG	(a	602	a4	582	22 74	070	22.84	259	22 82	992
120-MH	Mar 20/21	3361 8	30	G	b5a:	298	(a4	653	(a	234	c7b	359	a4	352
139-MH	Apr 11/12	3383 8	30	FG	(a4	880	(a4	708	(a4	321	b5a	738	c7b:	819
148-MH	Apr 12/13	3384 8	30	F	22 72	907	(a	756	(a4	371	b6a	755	c5b	840
71-H	Oct 13/14	3569 024	26	FG	a6	788	b5a	596	c7b	477	22 66	923	(a	755
318-B	Oct 17/18	3573 027	29	G	22 69	894	(a4	788	(a4	675	22.37	992	b5a	840
344-B	Nov 6/7	3592 989	30	VG	a4	423	(a4	746	(a4	661	c7b	335	a4	264
85-H	Nov 11/12	3597 964	30	FP	(b5a	555	22.93	985	a	907	b4a	420	a	370
98-H.	Dec 6/7	3633 977	30	F	a4	218	c7b	185	22 97	144	b1a	850	b7a	902
114-M .	Dec 8/9	3624 944	30	F	a4:	270	a4	279	a4	241	22 93	884	23 04	943
250-MH	Dec 15/16	3631 8	25	P	.. ..	451	..	608	..	580	B	002	a:	089
254-MH	1951 Jan 3/4	3650 8	30	FG	22 69	955	a4	520	(a4	519	23 00	329	a4	493
256-MH	Jan 7/8	3654 8	30	FG	22 69	061	(a	712	(a4	717	23 00	398	a4	578
124-M .	Jan 13/14	3660 8	30	F	a4	220	22 84	000	22 74	013		501	(a	705
263-MH	Feb 2/3	3680 8	30	P	..	750	22 93:	960	B	002	...	845	.. ..	130
268-MH	Feb 3/4	3681 8	30	FG	(a4	776	22.75	008	22 90	051	b2a	862	22.98	152
274-MH	Feb 7/8	3685 8	30	F	22 73	882	c5b	200	b	149	22 62	931	c2b	237
289-MH	Mar 3/4	3709 8	30	P	F	518	F	351	...	436	F	343	(a	747
358-B..	Mar 8/9	3714 675	30	FG		645	F	580	(b5a	671	F	425		848
291-MH	Apr 1/2	3738 8	30	P	.	286	.	743	a:	869	F	842	..	363
546-B	Oct 4/5	3925 010	30	G	(a	220	(a	678	22 93	073	22.60	044	a4	320
554-B	Oct 31/Nov 1	3951 951	30	G	22 63	929	22 67	971	(a4	405	b5a	507	b5a	892
23-S	Nov 5/6	3956 937	25	P	22 69	066	(a	210	F	651	F	593	22 81	998
35-S	Nov 7/8	3958 968	25	G	22 71	120	(a4	307	(a4	752	(a	628	22 87	042
44-S	Nov 8/9	3959 969	30	F	..	146	(a	355	(b7a	801	a2	645	22 92	063
47-S	Nov 29/30	3980 859	30	G	a4	700	a4	358	(a	834	22 39	004	a4	507
62-S	Dec 2/3	3983 893	30	FG	a8	780	(a	503	23 05	984	22.60	056	(a4	571
78-S	Dec 26/27	4007 901	30	FG	a8	416	(a	655	22 90	171	c8b	469	22.87	081
92-S	1952 Jan 3/4	4015 891	30	FG	a8	628	22 93	039	(a	565	(a	607	c7b	251
100-S.. .	Jan 23/24	4035 813	30	FG	22.72	156	22.63	995	(a4	550	22 50	949	a4	675
3-Bm	Jan 30/31	4042 820	30	G	b5a	342	b7a	331	(a4	897	22 53	070	c5b	823
391-MH	Feb 15/16	4058 695	30	G	a8	762	22.84	093	(a4	681	22 75	343	22.98	161
401-MH	Feb 24/25	4067 679	30	P	B	000	F	524		125	F	497	a4:	352
408-MH	Mar 24/25	4096 671	30	VP	..	769	.....	915	..	559	.. ..	996	B	968
412-MH	Mar 25/26	4097 659	30	FG	a8	795	22 84	962	(a4	607	22 48	013	23 10	989
420-MH	Apr 15/16	4118 672	30	FG	a4	352	22.71	971	(a4	646	b	374	a	435
434-MH	Apr 22/23	4125 684	30	FG	a4	537	b5a	307	22 58	993	c8b	495	a4	584
158-H	Oct 14/15	4300 985	30	VG	22 82	182	a4	719	(a4	658	b3a	509	a2	310
180-S	Oct 25/26	4311 989	30	G	a:	474	(a	247	c5b	202	a4	698	(a	543
193-S	Oct 26/27	4312 963	30	P	.. ..	499	.. ..	294	.. ..	250	.. ..	715	...	564
209-S	Nov 10/11	4327 934	30	FG	22 72	896	22 67	012	22 70	990	22.50	972	b5a	882
231-S	Nov 24/25	4241 883	30	P	F	266	.	681	F	679	..	212	23.01	179
255-S	Dec 9/10	4356 923	25	F	F	664	a	403	F	423	F	471	c5b	498
264-S	Dec 10/11	4357 910	30	F	(a	690	F	450	F	472		488	(a	519
290-S	Dec 22/23	4369 851	30	F	22 82:	007	22 84	023	B	062	.. ..	693	(a4	773
309-S	1953 Jan 8/9	4386 764	30	FG	a4	455	a	835	(b5a	898	22 26	984	22 98	132
331-S	Jan 16/17	4394 714	30	FG	a8	665	c7b	216	..	291	22 50	120	(a	301
359-S	Feb 6/7	4415 718	30	P	B	222	..	224	F	329	F	482	b5a	748
375-S	Feb 17/18	4426 761	30	FG	(a	514	(a4	754	(a	875	a4	672	22 98	982
393-S	Mar 5/6	4442 649	30	F	22 66	935	(a	517	(b7a	660	22 93	945	23 10:	320
409-S .	Mar 6/7	4443 661	30	G	22 66	962	(a4	565	(b7a	710	22 30	962	a4	342
467-S .	Mar 17/18	4454 646	30	FG	a	253	b7a	092	(a4	253	22 68	151	a4	575
468-S	Mar 17/18	4454 676	10	F	F	254	22 71	094	(b	255	22 84	152	.. ..	576
598-S	Oct 9/10	4660 979	44	G	a8	720	22 55	993	(a	453	a4	699	22 84	960
629-S	Oct 12/13	4663 990	25	G	(a4	800	a	138	(a	601	(a	.751	22 84	024
891-B	Dec 5/6	4717 836	30	G	a4	227	(a	721	(a	263	(a	677	22.87	.212
901-B.	Dec 6/7	4718 848	30	G	b5a	254	(a	770	(a	313	a4	694	c5b	168
641-S .	Dec 7/8	4719 902	30	G	b5a	281	a	820	(a	365	a4	712	23 07	189
649-S	1954 Feb 4/5	4778 681	30	FG	(a4	839	a	641	b	270	a4	723	a4	461
661-S	Feb 5/6	4779 688	30	FG	a	866	(a4	.689	(a	320	(a	740	a4	482
671-S	Feb 6/7	4780 680	30	F	.. ..	892	(a	737	F	369	(b7a	757	(a	503
672-S	Feb 7/8	4781 779	30	F	22 63	921	(a	790	(a	424	b8a	776	(a	527
678-S	Feb 8/9	4782 843	30	VP	.. ..	949	. .	.841	F	476	...	794	..	549
683-S	Feb 9/10	4783 876	30	F	22 66	977	(a	890	(a	527	b5a	812	a2	571
693-S	Feb 27/28	4801 774	30	VP	..	451	F	749	F	412	22 7 :	120	.....	.952
700-S.	Feb 28/Mar 1	4802 644	30	VG	a8	474	(a2	791	(a4	455	22 52	135	22.92	970
851-S .	Nov 2/3	5049 946	20	FG	22 63	026	(a	658	(a	679	b	387	b7a	225
893-S	1955 Jan 23/24	5131 726	21	P	..	193	.	582	..	722	.	793	.. ..	963
900-S	Mar 24/25	5191 691	30	VG	a8	782	a	459	(a4	686	b	825	23 04	237
1122-S .	Oct 20/21	5401 963	30	FP	a4	353	(a	549	22 74	080	F	440	a4	706
1143-S	Oct 23/24	5404 976	25	FG	a4	433	(a	694	23 05	229	23 02	492	a	770
1167-S	Dec 14/15	5456 905	30	VG	a8	809	a	185	(a4	795	23 02	385	23 10	873
1338-S	1957 Jan 31/Feb 1	5870 836	25	F	(a	776	22.89	048	(a	256	23 00	503	a4	670
1355-S	Feb 4/5	5874 757	25	VG	a8	880	c7b	236	(a4	450	a4	570	(a4	753
1358-S	Feb 4/5	5874 828	25	VG	b7a	882	b	239	(a	453	a4	571	(a4	754
32-A	1958 Jan 15/16	6219 780	30	P	..	022		791	(a	504		503	..	085
3216-A	1959 Mar 3/4	6631 766	25	VP	B	938	...	561	(b	869	..	587	b:	840
3584-S	1960 Apr 18/19	7043 707	25	FG	F	853	b5a	328	22 97	232	a4	670	b:	594
3721-S	Nov 23/24	7263 013	25	G	a8	663	(a	851	22 97	072	a4	441	23 04	254
3735-A	Dec 22/23	7292 780	165	P	....	452	.. ..	279	...	543	...	953	...	886
4054-S .	1962 Nov 4/5	7974 028	35	G	a4	502	22 67	968	b5a	217	b5a	667	b5a	363
4196-S .	1963 Mar 18/19	8107 723	35	F	22 63	045	b	385	(a	826	22 50	966	22.98	204
4199-S	Mar 19/20	8108 648	35	P	.. ..	069	..	428	.. ..	872	.. ..	982	.. ..	224
PH-4213-S .	Mar 20/21	8109 651	35	FP	22 77	0 096	F	0 476	23 05	0 921	22 17	0 999	23 10:	0 245

TABLE A2

V MAGNITUDES AND PHASES FOR 17 CEPHEIDS

Plate	Date	J. D.⊙ 2430000+	Exp. Time (min)	Qual.	V 1 *V*	V 1 Phase	V 3 *V*	V 3 Phase	V 4 *V*	V 4 Phase	V 5 *V*	V 5 Phase	V 6 *V*	V 6 Phase	V 8 *V*	V 8 Phase
PH-569-B....	1951 Nov 3/4	3953.918	60	G	21.65:	0.319	.....	0.384	(21.7	0.357	.....	0.736	(21.7	0.872	21.61:	0.080
574-B....	Nov 4/5	954.914	55	VG	21.65	.345	21.34	.396	21.63	.363	21.80:	.757	21.52	.905	21.62	109
192-S....	1952 Oct 26/27	4312.938	30	F	(21.3	.438	21.12	.488	(21.4	.710	21.45:	463	(21.4	.736	(21.4	.530
256-S....	Dec 9/10	356.948	20	F	(21.3	.555	21.07	.991	(21.3 :	.859	21.12	.410	(21.4	.190	(21.4	.811
395-S....	1953 Mar 5/6	442.669	10	VP	.....	.733	.....	.971	.....	.096	.....	.256	.....	.023	.....	.307
662-S....	1954 Feb 5/6	779.720	45	FG	21.43	.293	21.35	.824	21.47	.895	21.59	.510	21.63	.162	21.60	.118
701-S....	Feb 28/Mar 1	802.681	60	VG	21.96	.876	20.72	.087	21.99	495	20.94	.004	21.84	.921	(22.0	.786
1155-S....	1955 Oct 24/25	5406.018	40	G	21.53	.199	20.99	.984	21.64	.245	21.27	.991	21.8 :	.859	21.56	.449
1177-S....	Dec 15/16	457.887	45	G	21.64	.517	21.43	.577	21.75	.949	21.14	.107	(21.8	.573	(21.9	.859
1337-S....	1957 Jan 31/Feb 1	870.806	45	FG	21.53	.004	21.18	.297	21.53	.379	21.11	.995	(22.0	.219	(22.0	.878
1353-S....	Feb 4/5	874.685	40	G	21.38	.102	20.95	.341	21.45:	.480	21.08	.078	(21.6	.347	21.42	.991
31-A....	1958 Jan 15/16	6219.748	50	FP	(21.3	.866	21.2	.286	(21.3	.488	21.21	.505	(21.5	.750	.....	.035
3217-A....	Mar 3/4	631.792	40	P	.....	.331	21.2	.996	.....	.245	21.3	.374	(21.7	.367	(21.4	.030
3583-S....	1960 Apr 18/19	7043.682	40	FG	(21.5	.792	21.25	.705	21.20	.998	21.15	.240	21.54	.979	21.49	.019
3710-S....	Oct 17/18	226.005	15	FG	(21.3	.423	21.09	.789	(21.3	.757	20.95	.163	(21.3	.004	(21.3	.327
3722-S....	Nov 23/24	263.041	32	G	21.46	0.363	21.12	0.212	(21.7	0.724	21.25	0.961	21.72	0.228	21.72	0.405

Plate	Date	J. D.⊙ 2430000+	Exp. Time (min)	Qual.	V 15 *V*	V 15 Phase	V 19 *V*	V 19 Phase	V 21 *V*	V 21 Phase	V 25 *V*	V 25 Phase	V 29 *V*	V 29 Phase	V 33 *V*	V 33 Phase
PH-569-B....	1951 Nov 3/4	3953.918	60	G	21.24	0.101	21.23	0.624	(21.7	0.588	21.26	0.860	21.15	0.993	21.41	0.567
574-B....	Nov 4/5	954.914	55	VG	21.42	.130	21.40	636	.....	614	.....	.881	.....	.023	.....	.584
192-S....	1952 Oct 26/27	4312.938	30	F	(21.4	799	20.71	.029	(21.4	.676	21.25	481	(21.4	.875	21.13	.950
256-S....	Dec 9/10	356.948	20	F	21.22	111	21.15	.569	(21.4	790	.....	.415	21.3	.209	21.35	732
395-S....	1953 Mar 5/6	442.669	10	VP	.....	665	.....	.621	.....	.960	.....	.234	.....	.807	.....	.256
662-S....	1954 Feb 5/6	779.720	45	FG	21.73	709	21.21	757	(21.7	492	21.31	.389	21.17	.023	21.49	.249
701-S....	Feb 28/Mar 1	802.681	60	VG	21.70	.393	20.63	.039	21.80	.073	21.31	.876	21.90	719	21.70	657
1155-S....	1955 Oct 24/25	5406.018	40	G	21.66	.372	21.20	442	(21.8	.345	21.51	684	21.33	.006	21.43	.384
1177-S....	Dec 15/16	457.887	45	G	21.48	.917	20.94	.079	21.84	658	21.56	784	21.7 :	.578	21.50	.306
1337-S....	1957 Jan 31/Feb 1	870.806	45	FG	21.50	.222	21.26	146	(22.0	.110	21.46	.550	21.26	.094	(21.8	647
1353-S....	Feb 4/5	874.685	40	G	(21.6	.338	21.10	193	(21.7	.208	21.47	632	21.49	.212	21.50:	.716
31-A....	1958 Jan 15/16	6219.748	50	FP	.....	.320	21.2	427	21.5	.942	20.8	.957	21.3	670	(21.6	.851
3217-A....	Mar 3/4	631.792	40	P	.....	.899	21.4	484	21.6	.372	21.4	.703	21.2	.160	21.3	177
3583-S....	1960 Apr 18/19	7043.682	40	FG	21.30	.173	21.15	.538	(21.5	798	21.23	446	21.6 :	644	21.44	.500
3710-S....	Oct 17/18	226.005	15	FG	(21.3	606	20.86	775	(21.3	413	21.11	.316	21.42:	170	(21.3	741
3722-S....	Nov 23/24	263.041	32	G	21.50	0.709	21.06	0.230	(21.7	0.351	20.85	0.102	21.46	0.293	21.50	0.400

Plate	Date	J. D.⊙ 2430000+	Exp. Time (min)	Qual.	V 34 *V*	V 34 Phase	V 40 *V*	V 40 Phase	V 42 *V*	V 42 Phase	V 46 *V*	V 46 Phase	V 54 *V*	V 54 Phase
PH-569-B....	1951 Nov 3/4	3953.918	60	G	21.56	0.986	(21.7	0.065	(21.7	0.502	21.55	0.541	(21.7	0.934
574-B....	Nov 4/5	954.914	55	VG	.....	.013	.....	.113	.....	.551	.....	.558	(21.7	.955
192-S....	1952 Oct 26/27	4312.938	30	F	(21.4	.499	(21.4	.293	(21.4	.249	(21.4	.714	(21.4	.564
256-S....	Dec 9/10	356.948	20	F	(21.4	.665	(21.4	.404	(21.4	.424	21.4 :	.471	(21.4	.499
395-S....	1953 Mar 5/6	442.669	10	VP	.....	.936	.....	.518	.....	.661	.....	.945	.....	.320
662-S....	1954 Feb 5/6	779.720	45	FG	(21.7	.866	21.85:	.691	(21.8	.322	21.68	.741	(21.8	.483
701-S....	Feb 28/Mar 1	802.681	60	VG	22.0 :	.475	(22.0	.793	(22.0	.457	21.44	.136	22.1 :	.992
1155-S....	1955 Oct 24/25	5406.018	40	G	(21.6	.461	(21.8	.744	21.8 :	.280	21.59	.510	(21.8	.792
1177-S....	Dec 15/16	457.887	45	G	(21.9	.835	(21.9	.232	(21.9	.844	21.50	.402	(21.8	.894
1337-S....	1957 Jan 31/Feb 1	870.806	45	FG	(22.0	.776	21.81	.046	.....	.255	21.85	.502	(22.0	.669
1353-S....	Feb 4/5	874.685	40	G	(21.6	.878	(21.6	.232	(21.7	.446	21.60:	.569	(21.7	.751
31-A....	1958 Jan 15/16	6219.748	50	FP	21.5	.021	(21.5	.790	21.7	.503	21.6	.502	(21.3	.084
3217-A....	Mar 3/4	631.792	40	P	(21.5	.939	(21.7	.562	(21.6	.870	21.4	.587	(21.7	.840
3583-S....	1960 Apr 18/19	7043.682	40	FG	(21.5	.852	21.6 :	.326	21.6 :	.230	21.37	.670	(21.5	.593
3710-S....	Oct 17/18	226.005	15	FG	(21.3	.683	(21.3	.075	(21.4	.243	21.35:	.805	(21.4	.467
3722-S....	Nov 23/24	263.041	32	G	(21.8	0.664	(21.8	0.892	21.76	0.073	21.52	0.442	21.59	0.254

TABLE A3

B MAGNITUDES FOR 8 VERY BRIGHT BLUE VARIABLES AND FOR THE ECLIPSING BINARY

Plate	Date	J D$_{\odot}$ 2400000+	Exp. Time (min)	Qual.	V 12	V 14	V 22	V 35	V 37	V 38	V 52	V 53	V 55 *B*	V 55 Phase
S-Ri. .	1910 Feb 7/8	18710 8	120	G	20 7 :	20 9 :		.. .		19 5 :	20 6 :	20 8		
S-169-P	1912 Nov 8/9	19715 8	210	G	21 06	20 9 :	.. .	21 5 :	.. .	18 90	20 6 :	20 6		
S-Ri. ..	1916 Feb 2/3	20896 8	420	VG	21 29	20 9	21 2 :	21 2 :	21 2 :	18 62	20 3	20 7		
S-307-P	1917 Oct 19/20	21521 8	100	FG	21 7 :	20 7 :	.. .	21 5 :	.. .	18 85	20 5 :	20 7 :		
S-Ri. .	Dec 12/13	21575 8	130	FG	21 6 :	20 7 :	21 3 :		21 3 :	18 55	20 3 :	20 8 :		
S-109-Δ	1920 Dec 10/11	22669 8	60	F	(21 2				20 3 :	18.45				
S-116-Δ	Dec 12/13	22671 8	35	FP	.. ..	.. .			.. ..	(B)	.. ..	.. .		
S-120-Δ	1921 Jan 4/5	22694 8	60	G	21 37	20 7 :	.. .	.. .	19 60	18 74	20 42	20 9		
S-121-Δ	Jan 4/5	22694 8	560	G	21 37	20 85:	21 2 :	20 7	19 45	18 90	20 25	20 8		
S-123-Δ	Jan 5/6	22695 8	240	FG	21 4	20 9 :		20 7 :	19 5 :	18 90	20 35	20 8 :		
S-398-H	1924 Oct 27/28	24086 921	90	FG	21 36	20 9 :		(21	21 3 :	18 55	20 37	20 8		
S-403-H	Oct 30/31	24089 880	110	F	21 21:	20 7 :	.. .	(21 5	.. .	18 55	20 30:	(20 9		
S-413-H	Nov 24/25	24114 824	105	FG	21 21:	20 7	21 2 :	(21 5	21 0 :	18 60	20 25	(20 9		
S-419-H	1925 Jan 17/18	24168 806	90	FP	21 2 :	20 8 :	.. .	.. .	.. .	18 30	.. .	.. .		
S-425-H	Jan 26/27	24177 748	85	G	21 30	20 9	21 2 :	21 2 :	21 2	18 00	20 5	20 8		
S-435-H	Feb 15/16	24197 798	90	F	21 45	20 65	21 3 :	21 2 :	21 0	18 40	20 37	20 7		
S-201-B	Feb 18/19	24200 70	31	FG	.. ..	.. .	.. .	.. .		18 10	.. ..	.. .		
S-443-H	Feb 28/29	24210 841	90	F	21 00:	20 7 :	21 2 :	(21 5	.. .	17 80	20 22	20 8		
S-454-H	Mar 17/18	24227 661	80	G	21 00	20 6 :	20 95:	(21 5	21 5	18 30	20 22	20 7		
S-11-SS	Nov 14/15	24469 8	90	F	(21 0	.. .				18 20	20 3 :	.. .		
S-27-SS.	Dec 20/21	24505 8	90	FG	21 1 :	20 8 :		..	.. .	18 50	20 3	(20 8		
S-1060-H	1930 Jan 21/22	25998 865	120	F	20 9	.. .	.. .	(21	19 0	19 0	20 4	20 8 :		
S-1831-H	1938 Nov 19/20	29223 026	75	G	21 30	20 6	21 0	21 2	21 05	19 70	20 6 :	20 8	.. ..	. ...
PH-5-H.	1949 Jan 27/28	32944 8	30	VP	20 29	20 70	20 32	22 2 :	21 29	19 76	20 37	20 67	21 67:	0 232
PH-19-H	Feb 18/19	32966 732	45	P	20 47	20 75	20 31	22 1 :	21 40	19 68	20 42	20 70	21 63:	846
PH-30-H	Feb 21/22	32969 710	45	P	20 50	20 71	20 25	22 3 :	21 35	19 76	20 42	20 77	21 81:	337
PH-39-H..	Feb 25/26	32973 664	45	P	20 39	20 76	20 18	22 4 :	21 32	19 72	20 50	20 70	22 38:	989
PH-36-MH.	1950 Jan 15/16	33297 8	35	FG	20 50	20 80	20 38	22 61	21 43	19 81	20 47	20 43	21 90	415
PH-120-MH	Mar 20/21	33361 8	30	G	19 84	20 75	20 42	22 86	21 42	19 83	20 55	20 39	21 95	964
PH-139-MH	Apr 11/12	33383 8	30	FG	20 71	20 73	20 40	22 48	21 43	19 72	20 45	20 40	22 24	590
PH-148-MH	Apr 12/13	33384 8	30	F	20 48	20 72	20 45	22 50	21 48	19 85	20 50	20 48	21 91	755
PH-71-H.	Oct 13/14	33569 024	26	FG	19 62	20 68	20 59	22 88	21 34	19 78	20 50	20 45	21 98	119
PH-318-B	Oct 17/18	33573 027	29	G	20 68	20 71	20 51	22 54	21 48	19 81	20 70	20 34	21 86	779
PH-344-B	Nov 6/7	33592 989	30	VG	19 81	20 66	20 85	22 67	21 25	19 73	20 57	20 33	22 00	069
PH-85-H.	Nov 11/12	33597 964	30	FP	20 63	20 75	20 69	22 73	21 44	19 81	20 55	20 45	21 97:	889
PH-98-M	Dec 6/7	33622 977	30	F	20 48	20 70	20 70	22 67	21 44	19 79	20 57	20 26	22 35	012
S-75-S. ..	Dec 8/9	33624 929	25	G	20 8	20 7	21 0	.. ..	.. ..	19 81	20 5	20 5	.. ..	...
PH-114-M .	Dec 8/9	33624.944	30	F	20 72	20 69	20 63	22 73	21 43	19 80	20 65	20 30	21 69	336
PH-250-MH	Dec 15/16	33631.8	25	P	20 31	20 65	20 65	.. ..	21 48	19 89	20 62	20 42	22 38:	466
PH-254-MH	1951 Jan 3/4	33650 8	30	FG	20 44	20 62	20 66	22 89	21 57	19 78	20 68	20 42	21 93	598
S-82-S. ...	Jan 6/7	33653 835	30	G	20 31	20 85:	20 90	.. ..	21 2	19 83	20 5	20 5	.. ..	...
PH-256-MH	Jan 7/8	33654 8	30	FG	20 18	20 66	20 70	22 73	21 31	19 91	20 56	20 50	21 74	257
PH-124-M .	Jan 13/14	33660 8	30	F	19 96	20 70	20 67	22 7 :	21 31	19 91	20 47	20 42	21.69	246
PH-263-MH	Feb 2/3	33680 8	30	P	19 98	20 69	20 82	.. ..	21 43	20 04	20 62	20 60	(f)	543
PH-268-MH	Feb 3/4	33681 8	30	FG	20 38	20 67	20 84	22 90	21 43	19 97	20 67	20 55	21 77	708
PH-274-MH	Feb 7/8	33685 8	30	F	19 54	20 60	20 97	22 70	21 42	19 93	20 70	20 55	21 90	367
PH-289-MH	Mar 3/4	33709 8	30	P	20 12	20 69	20 88	22 5 :	21 42	20 05	20 67	20 57	21 72:	323
PH-358-B..	Mar 8/9	33714 675	30	FG	19 19	20 67	20 80	22 61	21 32	19 80	20 58	20 52	22 12	109
PH-291-MH	Apr 1/2	33738 8	30	P	19 79	20 72	20 97	22 5 :	21 40	19 89	20 67	20 62	.. ..	...
PH-546-B	Oct 4/5	33925 010	30	G	19 69	20 77	21 14	22 73	21 27	19 73	20 60	20 47	21 69	795
PH-554-B	Oct 31/Nov 1	33951 951	30	G	20 26	20 80	21 16	22 67	21 25	19 76	20 67	20 53	21 87	235
PH-23-S	Nov 5/6	33956 937	25	P	20 03	20 70	21 12	22 58	21 18	19 88	20 52	20 41	22 15	.057
PH-35-S	Nov 7/8	33958 968	25	G	20 01	20 70	21 15	22 65	21 20	19 85	20 67	20 40	21 98	392
PH-44-S	Nov 8/9	33959 969	30	F	20 28	20 71	21 15	22 67	21 26	19 82	20 66	20 46	22 22	557
PH-47-S	Nov 29/30	33980 859	30	G	19 81	20 74	21 17	22 48	21 30	19 85	20 65	20 36	22 45	000
PH-62-S	Dec 2/3	33983 893	30	FG	19 93	20 69	21 16	22 61	21 25	19 81	20 74	20 46	22 47	500
PH-78-S	Dec 26/27	34007 901	30	FG	20 89	20 78	21 18	22 73	21 17	19 74	20 60	20 37	21 97	457
PH-92-S	1952 Jan 3/4	34015 891	30	FG	20 91	20 72	21 21	22 59	21 14	19 76	20 62	20 40	21 68	774
PH-99-S.	Jan 19/20	34031 872	16	P	18 45	20 7 :	21 1 :	.. ..	21 3	19 76	.. ..	.. ..	.. ..	...
PH-100-S	Jan 23/24	34035 813	30	FG	20 41	20 79	21 14	22 35	21 32	19 80	20 66	20 46	22 20	057
PH 3-Bm..	Jan 30/31	34042 820	30	G	20 90	20 77	21 14	22 50	21 27	19 76	20 72	20 37	21 92	212
PH-391-MH	Feb 15/16	34058 695	30	G	20 03	20 55	21 30	22 54	21 35	19 73	20 70	20 47	21 78	829
PH-401-MH	Feb 24/25	34067 679	30	P	19.62	20 7 :	21 61	22 3 :	21 42	19.87	20 65	20 50	21 81:	310
PH-408-MH	Mar 24/25	34096 671	30	VP	19 90	.. ..	.. ..	.. ..	.. ..	19 63:	.. ..	.. ..	.. ..	...
PH-412-MH	Mar 25/26	34097 659	30	FG	20 25	20 58	21 30	22 31	21 19	19 75	20 62	20 57	21 75	251
PH-420-MH	Apr 15/16	34118 672	30	FG	21 04	20 62	21 44	22 29	21 25	19 72	20 60	20 58	21 80	715
PH-434-MH	Apr 22/23	34125 684	30	FG	21 13	20 64	21 38	22 58	21 22	19 67	20 60	20 72	21 75	871
PH-158-H	Oct 14/15	34300 985	30	VG	19 62	20 63	21 32	22 60	21 18	19 14	20 65	20 57	21 74	765
PH-180-S	Oct 25/26	34311 989	30	G	19 75	20 65	21 36	22 46	20 73	19 56	20 54	20 38	21 88	578
PH-193-S	Oct 26/27	34312 963	30	P	19 25	20 71	21 20	.. ..	20 97	19 56	.. ..	20 60:	.. ..	...
PH-209-S	Nov 10/11	34327.934	30	FG	20 89	20 61	21 18	22 48	21 12	19 57	20 62	20 43	21 81	206
PH-231-S	Nov 24/25	34341 883	30	P	19 33	20 63	21 16	22 3 :	21 18	19 57	.. ..	20 58:	22 45:	505
PH-255-S	Dec 9/10	34356 923	25	F	19 50	20 56	21 18	.. .	21 12	19 54	20 70	20 53	22 41	984
PH-264-S	Dec 10/11	34357 910	30	F	19 28	20 67	21 18	22 2 :	21 09	19 62	20 55	20 46	21 84	147
PH-265-S	Dec 10/11	34357 923	7	FG	19 20	20 65	21 18		21 07	19 60	20 60	20 48	.. ..	...
PH-290-S	Dec 22/23	34369 851	30	F	20 30	20 57	21 22	.. .	20 88	19 68	20 53	20 45	21 82	115
PH-309-S	1953 Jan 8/9	34386 764	30	FG	19 64	20 49	21 3	22 0 :	20 82	19 70	20 64	20 33	21 82	903
PH-331-S	Jan 16/17	34394 714	30	FG	20 21	20 55	21 6	22 1 :	20 90	19 74	20 63	20 37	21 74	213
PH-359-S	Feb 6/7	34415 718	30	P	18 99	20 60	21 36	22 3 :	20 68	19 75	.. ..	20 40:	21 82:	675
PH-375-S	Feb 17/18	34426 761	30	FG	20 15	20 49	21 20	22 10	21 09	19 72	20 65	20 52	22 30	495
PH-393-S	Mar 5/6	34442 649	30	F	20 10	20 56	21 18	21 7 :	21 02	19 73	20 68	20 46	21 94	114
PH-394-S	Mar 5/6	34442 662	3	FP	19 85	.. ..	.. ..	.. ..	.. ..	19 8 :	.. ..	.. ..	.. ..	...
PH-409-S	Mar 6/7	34443 661	30	G	19 37	20 64	21 33	21 78	21 01	19 71	20 70	20 40	21 72	.281
PH-410-S	Mar 6/7	34443 674	5	G	19 19	20 67	21 14	.. ..	20 92	19 73	20 63	20 51	.. ..	...
PH-467-S	Mar 17/18	34454 646	30	FG	20 53	20 67	21 20	21 75	21 06	19 65	20 69	20 45	21 95	092
PH-468-S	Mar 17/18	34454 676	10	F	20 28	20 69	21 20	22 16	21 07	19 71	20 70	20 55	21 84	0.097

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TABLE A3 -continued

Plate	Date	J D ⊙ 2400000+	Exp. Time (min)	Qual.	V 12	V 14	V 22	V 35	V 37	V 38	V 52	V 53	V 55 *B*	V 55 Phase
PH-598-S	1953 Oct 9/10	34660 979	44	G	19.29	20 59	21 59	21 44	21 03	19 77	20 60	20 38	22 02	0 101
PH-629-S	Oct 12/13	34663 990	25	G	19 66	20 64	21 63	21 31	20 89	19 76	20 55	20 39	21 87	597
PH-821-B	Dec 5/6	34717 836	30	G	18 52	20 47	21 44	21 20	21 05	19 73	20 62	20 40	22 40	472
PH-901-B	Dec 6/7	34718 848	30	G	19 24	20 55	21 60	21 31	20 87	19 74	20 62	20 40	21 88	638
PH-641-S	Dec 7/8	34719 902	30	G	19 24	20 56	21 36	21 16	20 88	19.74	20 66	20 41	21 72	812
PH-649-S	1954 Feb 4/5	34778 681	30	FG	19 33	20 65	21 57	21 20	20 86	19 80	20 55	20 45	22 49	500
PH-661-S	Feb 5/6	34779 688	30	FG	19 51	20 50	21 59	21 12	20 98	19 77	20 61	20 42	21 66	667
PH-671-S	Feb 6/7	34780 680	30	F	19 46	20 61	21 44	21 38	20 88	19 80	20 56	20 49	21 74	830
PH-672-S	Feb 7/8	34781 779	30	F	19 61	20 56	21 50	21 47	20 74	19 79	20 61	20 45	22 56	011
PH-678-S	Feb 8/9	34782 843	30	VP	19 62	.....	.. ..	.. ..	.. ..	19 82	.. ..	20 5 :	.. ..	...
PH-683-S	Feb 9/10	34783 876	30	F	19 11	20 53	21 59	21 31	20 89	19.77	20 52	20 47	21 92	357
PH-691-S	Feb 27/28	34801 676	10	VP	18 25	.. .		.		19 76				
PH-692-S	Feb 27/28	34801 760	10	P	18 30	20 6 :		.. .		19 80			.. ..	...
PH-693-S	Feb 27/28	34801 774	30	VP	18 46	20 7 :		21 3 :		19 78			21 86:	307
PH-695-S	Feb 27/28	34801 824	10	P	18 39	20 7 :				19 81				
PH-696-S	Feb 27/28	34801 876	10	VP	18 35	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	.. ..	...
PH-700-S	Feb 28/Mar 1	34802 644	30	VG	18 39	20 63	21 24	21 08	21 22	19 76	20 58	20 56	22 45	450
S-247-S	Mar 25/26	34827 741	20	FG	18 67:					19 8 :	20 6 :			
S-250-S	Mar 26/27	34828 651	30	G	19 20:					19 65:	.. .			
S-251-S	Mar 26/27	34828 709	25	FG	19 23:					19 65:	20 5 :			
S-254-S	Mar 26/27	34828 768	25	FG	19 01:					19 55:	20 5 :			
S-255-S	Mar 26/27	34828 832	25	FG	19 01:					19 85:	20 6 :			
S-256-S	Mar 26/27	34828 853	21	F	18 68:					19 45:	.. .			
S-257-S	Mar 27/28	34829 651	25	G	18 93				.. .	19 75:	20 6 :			.
S-259-S	Mar 27/28	34829 714	25	G	18 59:				21 3 :	19 70:	20 6 :			
S-261 S	Mar 27/28	34829 772	25	FG	19 10:					19 75:	20 7 :			
S-262-S	Mar 27/28	34829 845	25	FG	19 10:				.	19 65:	20 6 :	.		
S-264-S	Mar 28/29	34830 649	25	FG	19 10:					19 9 :	20 6 :			
S-266-S .	Mar 28/29	34830 702	25	FG	19 2 :	.. .	.. .	.. ..	.. .	19 8 :	.. ..	.. ..		
PH-725-S	Apr 7/8	34840 667	5	G	19 04	20 7 :	21 2 :	21 08	21 2 :	19 74	20 56	20 59	.. ..	...
PH-851-S	Nov 2/3	35049 946	30	FG	16 46	20 60	21 69	21 63	20 94	19 79	20 65	20 47	21 98	212
PH-893-S	1955 Jan 23/24	35131 726	21	P	16 90	.. ..	.. ..	.. ..	20 9	19 86	.. ..	20 45:	21 7 :	691
PH-900-S	Mar 24/25	35191 691	30	VG	19 82	20 70	21 30	21 40	21 27	19 78	20 61	20 51	22 05	575
PH-916-S	Mar 28/29	35195 645	8	VP	19 62					19 8 :				
PH-917-S	Mar 28/29	35195 659	8	VP	19 59					19 85:				
PH-918-S	Mar 28/29	35195 673	8	V P	19.57	.. .				19 9 :				
PH-919-S	Mar 28/29	35195 687	8	VP	19 66	20 6 :				19 9 :				
PH-920-S	Mar 28/29	35195 701	8	VP	19 61	20 8 :				19 9 :				
PH-921-S	Mar 28/29	35195 725	8	VP	19 61					19 85:			..	
PH-922-S	Mar 28/29	35195 728	8	P	19 56	.. .	.			19 85:	.			
PH-923-S	Mar 28/29	35195 742	8	P	19 57	20 7 :	.			19 85:		.		
PH-924-S	Mar 28/29	35195 756	8	P	19 61	20 7 :				.. .				.
PH-925-S	Mar 28/29	35195 770	8	P	19 57	20 7 :		.		19 8 :				
PH-926-S	Mar 28/29	35195 784	8	P	19 64	20 7 :			.. .	19 85:				
PH-927-S	Mar 28/29	35195 798	8	P	19 57	20 7 :			21 0 :	19 8 :				
PH-933-S	Mar 29/30	35196 655	5	VP	19 62	20 6 :			20 9 :	19 85:				
PH-934-S	Mar 29/30	35196 672	5	VP	19 68	.. .			.. .	19 9 :				
PH-935-S	Mar 29/30	35196 690	5	VP	19 55	20 6 :			20 8 :	19 9 :	.. .	.. .		
PH-936-S	Mar 29/30	35196 703	5	FG	19 59	20 7 :			20 9 :	19 9 :	20 6 :	20 5		
PH-938-S.	Mar 29/30	35196 758	5	FG	19 62	20 7 :	.. ..	.. ..	20 8 :	19 9 :	20 6 :	20 6	.. ..	...
PH-1122-S	Oct 20/21	35401 963	30	FP	19 52	20 52	21 69	21 78	20 81	19 90	20 62	20 38	21 94:	233
PH-1143-S	Oct 23/24	35404 976	25	FG	19 51	20 55	21 65	21 75	20 74	19 92	20 63	20 32	21 78	730
PH-1167-S	Dec14/15	35456 905	30	VG	20 29	20 49	21 44	21 80	20 88	19 78	20 70	20 40	21 85	289
PH-1338-S	1957 Jan 31/Feb 1	35870 836	25	F	21 75	20 90	21 44	21 31	21 19	19 89	20 57	20 35	22 41:	515
PH-1355-S	Feb 4/5	35874 757	25	VG	21 85	20 77	21 44	21 16	21 12	19 82	20 67	20 31	21 78	161
PH-1358-S	Feb 4/5	35874 828	25	VG	21 80	20 87	21 59	21 27	21 12	19 87	20 62	20 42	21 89	173
PH-32-A .	1958 Jan 15/16	36219 780	30	P	(21 5	20 80	21 60	21 2 :	21 12	20 08	20 3	20 7 :		
PH-3216-A	1959 Mar 3/4	36631 766	25	VP	(21 6	20 80	(21 6	21 4 :	19 82	20 00	20 5	20 5 :	.. ..	...
PH-3584-S	1960 Apr 18/19	37043 707	25	FG	22 20	20 71	21 62	21 29	19 99	19 75	20 30	20 47	21 87	834
PH-3721-S	Nov 23/24	37263 013	25	G	22 05	20 70	21 62	20 86	19 52	19 75	20 34	20 46	22 52	981
PH-3735-A	Dec 22/23	37292 780	165	P	22 0 :	20 71	21 80	.. ..	19 54	.. ..	20 27	20 40:	.. ..	...
PH-4054-S	1962 Nov 4/5	37974 028	35	G	22 10	20 71	21 61	20 85	20 03	19 81	20.73	20 37	21 74	174
PH-4196-S	1963 Mar 18/19	38107 723	35	F	22 40	20 70	21 74	20 75	19 87	19 83	20 52	20 25	21 97	210
PH-4199-S	Mar 19/20	38108 648	35	P	(21 6	.. ..	.. ..	.. ..	.. ..	19 85:	.. ..	.. ..	.. ..	. ...
PH-4213-S	Mar 20/21	38109 651	35	FP	(22 3	20 75	21 76	20 82	19 92	19 85	20 52	20 33	22 26	0 528

TABLE A4

V MAGNITUDES FOR NON-CEPHEID VARIABLE STARS

Plate	J.D. 2400000+	V 2	V 7	V 9	V 11	V 12	V 14	V 16	V 22	V 27	V 30	V 31	V 32	V 35
PH-569-B......	33953.916	.....	20.87	20.52	21.18:	19.29	19.71	20.23	20.71	21.14	20.94	21.19	21.16	(21.7
PH-574-B......	954.912	20.92	20.75	20.48	21.12	19.20	19.62	20.25	20.76	.....	20.88	.....	.....	.....
PH-192-S......	34312.937	21.2	21.14:	20.59	20.88	18.80	19.65	20.87	20.92	21.40	20.93	21.08	21.04	(21.4
PH-256-S......	356.944	21.10	21	21.0	21.25	18.28	19.45	21.00	21.20	21.05	20.8	20.95	21.15	21.3
PH-395-S......	442.667	.....	.....	.....	.....	19.45:	19.50:	.....	(20.5	.....	(20.3	.....	.....	.....
PH-662-S......	779.717	21.47	20.64	20.85	21.33	18.30	19.45	20.92	21.18	21.38	20.65	21.41	21.35	21.44
PH-701-S......	802.679	21.36	20.30	20.78	21.32	17.40	19.57	21.07	21.11	21.35	20.49	21.31	21.08	21.57
PH-1155-S.....	35406.017	21.39	21.47	20.60	21.10	19.41	19.60	21.23	21.43	21.38	20.73	21.48	21.40	21.63
PH-1177-S.....	457.883	21.48	21.40	20.97	21.22	19.79	19.89	21.43	21.45	21.43	20.76	21.31	21.36	21.86
PH-1337-S.....	870.802	21.18	20.60	20.64	21.31	21.53	19.79	20.17	21.51	21.25	20.61	21.08	21.38	21.66:
PH-1353-S.....	874.681	21.01	20.72	20.79	21.07	21.34	19.84	20.21	21.35	21.27	20.65	21.50:	21.45:	21.29
PH-31-A.......	36219.744	21	.....	20.6	21.2	21.1	19.8	21.3	21.3	21.3	21.0	21.3	21.5	.....
PH-3217-A.....	631.790	21.2	21.0	20.1	21.2	(21.6	19.8	21.0	21.3	21.3	20.8	21.3	21.2	.....
PH-3583-S.....	37043.683	21.18	21.23	20.32	21.15	21.27	19.34	21.18	21.50	21.10	20.41	21.15	21.15	21.18
PH-3710-S.....	226.004	21.11:	20.98:	20.39	21.19	(21.3	19.29	20.79	21.00	21.22	20.90	21.31	21.34:	20.92
PH-3722-S.....	263.038	20.94	21.4 :	20.27	20.98	21.49	19.54	20.44	21.27	21.24	20.96	21.30	21.27	21.21

Plate	J.D.	V 36	V 37	V 38	V 39	V 41	V 43	V 52	V 53	V 56	V 57	V 60	V 61
PH-569-B......	33953.916	21.03	21.10	20.43	(21.4	20.25	20.49	20.33	19.62	20.40	21.88	21.25	20.70
PH-574-B......	954.912	.....	21.02	20.59	.....	.....	.....	20.24	19.53	20.47	20.94	21.11	20.58
PH-192-S......	34312.937	21.4 :	21.03	19.68	(21.4	20.41	20.98	20.37	19.59	19.94	20.40	20.65	21.12
PH-256-S......	356.944	21.10	21.15	20.42	21.15	20.40	20.70	21.00	19.80	20.58	20.38	20.55	21.2
PH-395-S......	442.667	.....	(20.5	19.7 :	.....	.....	.....	.....	.....	20.1 :	20.7 :	(20.1	(20.3
PH-662-S......	779.717	21.64	20.92	20.17	20.97	20.05	21.19	20.32	19.49	19.76	21.19	20.58	20.79
PH-701-S......	802.679	21.79	20.93	20.30	20.78	20.00	21.30	20.21	19.55	20.52	21.00	20.21	20.51
PH-1155-S.....	35406.017	21.8 :	21.28	20.76	21.05	20.20	21.16	20.81	19.70	20.33	20.74	20.66	20.76
PH-1177-S.....	457.883	21.66	21.01	20.30	21.14	20.19	21.20	20.54	19.87	19.78	20.80	20.65	20.96
PH-1337-S.....	870.802	20.74	21.42	20.59	21.31	20.31	20.80	20.68	19.85	20.07	20.89	20.20	21.08
PH-1353-S.....	874.681	20.83	21.33	20.47	21.15:	20.38	20.67	20.70	19.77	20.03	20.79	20.28	21.14
PH-31-A.......	36219.744	.....	21.2	20.7	21.2 :	20.4	20.8	20.6	19.7	20.15	(20.7	20.7	21.2
PH-3217-A.....	631.790	20.7	20.1	20.5	(21.4	20.4	20.9	20.2	19.9	20.11	20.35	20.7	21.1
PH-3583-S.....	37043.683	21.44	20.47	20.59	21.46	19.98	21.18	19.85	19.79	19.97	20.45	20.61	21.15
PH-3710-S.....	226.004	21.06:	19.67	20.53	21.14	20.21	20.45	19.73	19.52	20.15:	20.05	20.81	20.70
PH-3722-S.....	263.038	21.15	19.92	20.04	20.92	20.27	20.48	19.98	19.66	19.81	20.22	20.93	20.57

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