CEPHEIDS IN GALACTIC CLUSTERS. VI. U SGR IN M25

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ABSTRACT

Three-color photoelectric observations of 81 stars in the cluster M25 (IC 4725) are reported. These observations, fitted to the age-zero main sequence, give the apparent modulus of M25 as $m - M = 10\ 25$; the reddening determined from the three-color data as $E(B - V) = 0.49 \pm 0.05$ (m.e); the reddening determined from the spectral types and the observed $B - V$ values as $E(B - V) = 0.46 \pm 0.04$ (m.e); and the true modulus as $(m - M)_0 = 8\ 78 \pm 0.15$. The classical cepheid U Sgr ($P = 6^{d}744925$), assumed to be a member of the cluster by P. Doig in 1925, was recently rediscovered by Irwin to be in the vicinity of M25. Subsequently, Wallerstein and Feast have shown that U Sgr has the same radial velocity as selected cluster members in M25 and, therefore, that the variable is very likely a cluster member itself. Three-color observations of U Sgr were made and were combined with Eggen's data reduced to the B, V system. The mean magnitudes of U Sgr, corrected for reddening, are $\langle V_0 \rangle = 5.32$ $\langle B_0 \rangle = 5.91$, $\langle B_0 \rangle - \langle V_0 \rangle = 0\ 59$. The absolute magnitudes at mean light are $\langle M_{V_0} \rangle = -3.46$ and $\langle M_{B_0} \rangle = -2.87$.

I. INTRODUCTION

Peter Doig first pointed out (1925) that U Sgr might be a member of the galactic cluster M25. Irwin (1955) has recently rediscovered that U Sgr is near the center of M25 and has since emphasized the importance of cepheids in galactic clusters (1958, 1960). A preliminary report of Irwin's photometry of M25 and U Sgr has appeared in the *Astronomical Journal* (1958). Irwin's absolute magnitude of $\langle M_{B_0} \rangle = -3.25$ for U Sgr deviates by about 0.5 mag. from the period-luminosity relation defined by the four cepheids so far studied in galactic clusters. These are CF Cas (Sandage 1958), EV Sct (Arp 1958), DL Cas (Arp, Sandage, and Stephens 1959), and CV Mon (Arp 1960). Because Irwin has not published his data in detail, it seemed that the only way to check whether the displacement of U Sgr from the period-luminosity relation was real was to repeat the photometry of M25. The new photometry is reported in this paper.

II. THE PHOTOMETRIC DATA

The photoelectric observations were made during the months of July, August, and September, 1959, with the 60- and 100-inch telescopes on Mount Wilson. A few additional measures were made of U Sgr and of 11 of the cluster members with the 200-inch telescope diaphragmed to 90 inches by H. C. Arp and by the writer. The stars are identified in Figure 1, which is from an 8 × 10-inch photograph with a 103*a*-D plate and a yellow plexiglass filter taken with the 100-inch diaphragmed to 58 inches. The numbering system is that of Irwin, who very kindly supplied a marked chart of the region. Table 1 lists the adopted magnitudes of 81 stars reduced to the U, B, V system. Stars 91 and 150 were chosen as local standards. These were tied to standard stars on the U, B, V system on eight nights. The declination of M25 [$\delta(1950) = -19°\ 11'.7$] puts the cluster low in the south at Mount Wilson and directly over the Los Angeles lights at culmination; consequently, the photometry is not so precise as that reported in other papers of this series. The mean errors of a single observation of stars 91 and 150, derived from the internal consistency of the comparison with the U, B, V system, are $\epsilon_v = \pm 0.040$ (m.e.), $\epsilon_{B-V} = \pm 0.025$ (m.e.), $\epsilon_{U-B} = 0.017$ (m.e.). Because each star on the program was measured only once, no other estimate of the uncertainty of the tabulated values is available. Apparently, we cannot claim an accuracy for the

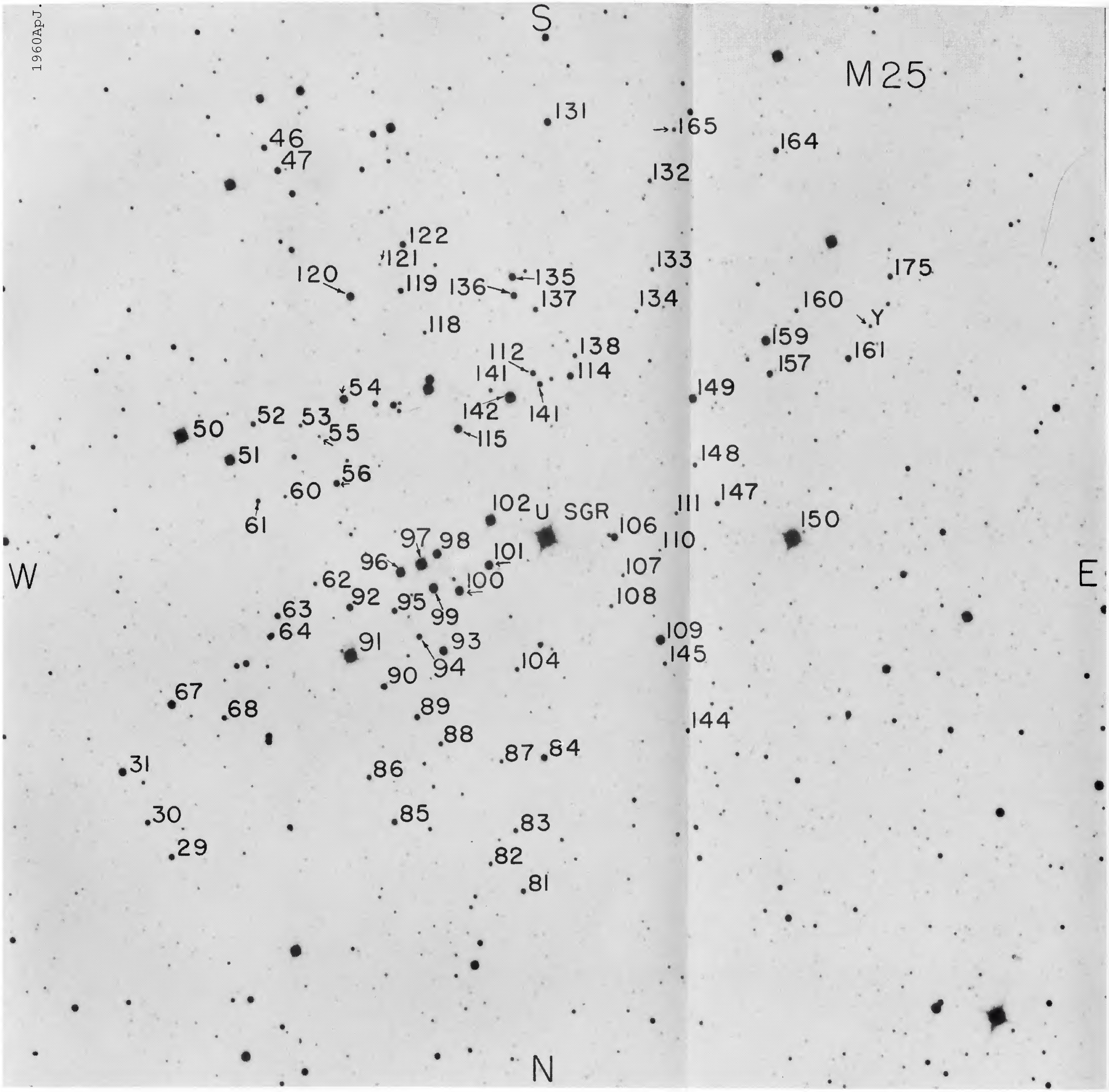

FIG. 1.—Identification chart for the program stars in M25. The [illegible] of Irwin. The reproduction is from a plate taken with the 100-inch telescope diaphragmed to 58 inches on Eastman 103*a*–D emulsion behind a yellow plexiglass filter.

1960ApJ...131..610S

TABLE 1

PHOTOELECTRIC OBSERVATIONS OF STARS IN M25

Star	V	$B-V$	$U-B$	$E(B-V)$	$E(U-B)$	V_0	$(B-V)_0$	$(U-B)_0$
29	12 08	0 48	+0 29	0 51	0 37	10 55	−0 02	−0 08
30	12 39	0 57	+0 31	63	47	10 98	− 05	− 16
31	10 71	0 34	+0 12	40	29	9 51	− 06	− 17
46	11 90	0 48	+0 38	45	33	10 55	+ 03	+ 05
47	11 44	0 41	+0 20	46	33	10 06	− 05	− 13
50	8 04	0 25	−0 17	37	27	6 93	− 12	− 44
51	9 25	0 36	−0 13	50	36	7 75	− 14	− 49
52	12 53	0 67	+0 38	72	55	10 37	− 05	− 17
53	14 02	1 91	. .	. .	.	.	. .	. .
54	10 55	0 40	+0 05	50	36	9 05	− 10	− 31
55	14 28	1 13	+0 77	. .	.	. . . .		. .
56	11 69	0 46	+0 26	50	36	10 19	− 04	− 10
60	14 15	0 85	+0 54					
61	13 12	1 37	+1 12					
62	13 79	0 82	+0 24					
63 .	11 94	0 43	+0 30	44	32	10 62	− 01	− 02
64*	11 74	0 58	+0 37	62	46	9 88	− 03	− 09
67	10 45	0 27	−0 08	37	27	9 34	− 10	− 35
68	12 78	1 37	+1 07	.	.	. . .	. .	.
81	12 67	0 66	+0 46	68	51	10 63	− 02	− 05
82	13 61	0 86	+0 37	48	35	12 17	+ 38	+ 02
83	13 03	0 73	+0 40	47	34	11 62	+ 26	+ 06
84	11 73	0 63	+0 44	48	35	10 29	+ 15	+ 09
85	12 10	0 48	+0 35	50	36	10 60	− 02	− 01
86	12 86	0 89	+0 42	54	40	11 24	+ 35	+ 02
87	13 84	0 91	+0 49	60	45	12 04	+ 31	+ 04
88	13 22	0 64	+0 55	.	.	. . .		.
89	12 16	0 49	+0 34	34	25	11 14	+ 15	+ 09
90	12 04	1 02	+0 53	. .	. .	.	. .	. .
91	8 10	0 30	−0 13	42	31	6 84	− 12	− 44
92	11 21	0 39	+0 14	46	33	9 83	− 07	− 19
93	10 38	0 36	0 00	46	33	9 00	− 10	− 33
94	12 23	1 37	+1 10	. .	.	. .	.	. .
95	12 18	0 54	+0 35	58	43	10 44	− 04	− 08
96	9 70	0 30	−0 12	42	31	8 44	− 12	− 43
97	8 80	0 35	−0 11	48	35	7 36	− 13	− 46
98	10 22	0 39	+0 02	49	36	8 75	− 10	− 34
99	9 89	0 36	−0 10	50	36	8 39	− 14	− 46
100	10 10	0 38	−0 07	51	37	8 57	− 13	− 44
101	10 27	0 41	+0 22	45	33	8 92	− 04	− 11
102	9 31	0 44	+0 01	55	41	7 69	− 11	− 40
104 .	13 28	0 74	+0 50	55	41	11 66	+ 19	+ 09
106*	11 26	0 40	+0 23	43	31	9 97	− 03	− 08
107†	14 60	1 62	+1 76	.		. . . .	. .	. .
108	14 14	0 90	+0 50	61	45	12 31	+ 29	+ 05
109	10 14	0 43	+0 22	48	35	8 70	− 05	− 13
110	14 85	0 90	+0 48	59	44	13 08	+ 31	+ 04
111	14 30	1 72	+1 89	. .	.	. . . .	. .	. .
112	12 27	0 52	+0 37	39	28	11 10	+ 13	+ 09
114	11 52	0 42	+0 20	0 47	0 34	10 11	−0 05	−0 14

* Star is double Measurement refers to both components

† Star 107 may be variable Tabulated values were obtained at JD 2436787 7 Arp's observation at JD 2436762 8 gives $V = 14\ 37$, $B - V = 1\ 80$, $U - B = 1\ 78$.

TABLE 1—*Continued*

Star	V	$B-V$	$U-B$	$E(B-V)$	$E(U-B)$	V_0	$(B-V)_0$	$(U-B)_0$
115.	10 74	0 45	+0 03	0 56	0 41	9 06	−0 11	−0 38
118	13 90	0 86	+0 32	44	32	12 58	+ 42	00
119	12 34	0 72	+0 40	46	33	10 96	+ 26	+ 07
120	10 57	0 39	+0 06	47	34	9 16	− 08	− 28
121	14 67	0 98	+0 44	57	42	12 96	+ 41	+ 02
122	11 85	1 58	+1 49	..	..	. .	.	..
131	11 25	0 38	+0 16	43	31	9 96	− 05	− 15
132	13 73	0 93	+1 40					
133	13 76	0 57	+0 57	..	.	.. ..	.	.
134	13 76	0 83	+0 48	57	42	12 05	+ 26	+ 06
135	11 02	0 46	+0 15	54	40	9 40	− 08	− 25
136	11 58	0 52	+0 29	56	41	9 90	− 04	− 12
137	12 71	0 73	+0 40	47	34	11 30	+ 26	+ 06
138	13 24	0 51	+0 26	56	41	11 56	− 05	− 15
141	12 50	1 54						.
142	9 07	0 38	+0 13	45	33	7 72	− 07	− 20
144	13 02	0 76	+0 52	57	42	11 31	+ 19	+ 10
145	13 68	0 85	+0 36	50	36	12 18	+ 35	00
147	12 89	0 64	+0 45	48	35	11 45	+ 16	+ 10
148	13 22	0 89	+0 38	50	36	11 72	+ 39	+ 02
149	10 42	0 42	+0 04	52	38	8 86	− 10	− 36
150	7 43	1 56	+1 34		..	.. .	..	..
157	11 92	0 57	+0 41	44	32	10 60	+ 13	+ 09
159	10 21	0 37	−0 07	49	36	8 74	− 12	− 43
160	13 50	0 84	+0 43	53	39	11 91	+ 31	+ 04
161	11 82	0 46	+0 35	42	31	10 56	+ 04	+ 04
164	12 22	0 54	+0 37	56	41	10 54	− 02	− 04
165	13 65	1 00	+0 41	54	40	12 03	+ 46	+ 01
175	12 56	0 43	+0 23	47	34	11 15	− 04	− 11
185	13 82	0 62	+0 44	0 48	0 35	11 38	+0 14	+0 09
Y	14 24	1 61	+1 90					

absolute photometry of greater than ±0.05 mag. for V and perhaps ±0.03 mag. for $B-V$ and $U-B$, but these errors are small enough for the present purpose.

Inspection of the 48-inch Sky Survey prints reveals that M25 is in a region of non-uniform absorption, with U Sgr in the middle of a dark lane. The reddening values derived in the usual way from the three-color data show differential absorption across the field. Where possible, the $E(B-V)$ value for each star was obtained from the normal $U-B=f(B-V)$ relation of Johnson and Morgan (1953), using a reddening line of the form $E(U-B)=E(B-V)[0.72+0.05\,E(B-V)]$ (Blanco 1955; Hiltner and Johnson 1956). Individual reddening values are given in the fifth and sixth columns of Table 1. The magnitude and colors corrected for reddening are given in the seventh, eighth, and ninth columns of Table 1. A factor of 3.0 was used to convert reddening to visual absorption.

The reddening can be independently estimated from the spectral types given for cluster members by Wallerstein (1957) and Feast (1957). The data are tabulated in Tables 2*A* and 2*B*. The mean value of the reddening determined from the spectral types and the measured $B-V$ values is $E(B-V)=0.43\pm 0.052$ (m.e.) from Feast's data and $E(B-V)=0.43\pm 0.063$ (m.e.) from Wallerstein's data. These are to be compared with the mean reddening values for the same stars derived by the three-color method of $E(B - V) = 0.46 \pm 0.040$ (m.e.) and $E(B - V) = 0.45 \pm 0.053$ (m.e.), respectively. The agreement is satisfactory and shows, among other things, that our color-index values are probably not greatly in error.

Because of differential reddening across the field, the quoted values of $E(B - V)$ do not apply to U Sgr itself. To estimate the correct value for U Sgr, all stars within a circle of 280″ radius about U Sgr have been studied, with the result that the reddening determined from the spectral types is $E(B - V) = 0.46 \pm 0.04$ (m.e.), and from the three-color method it is $E(B - V) = 0.49 \pm 0.05$ (m.e.). In the following analysis we adopt $E(B - V) = 0.47 \pm 0.05$ (m.e.) for U Sgr itself.

III. THE COLOR-MAGNITUDE DIAGRAM

The color-magnitude diagram for M25 is shown in Figure 2, where the magnitudes and colors, uncorrected for reddening, are plotted. The age-zero main sequence (Sandage 1957) is shown at an apparent modulus of $m - M = 10.25$. We estimate the precision of this fit to be ± 0.15 mag. A reddening of $E(B - V) = 0.47$ gives a true modulus of $(m - M)_0 = 8.84$. Figure 3 is the color-magnitude diagram with individual reddening

TABLE 2*A*

SPECTROSCOPIC MODULI AND REDDENING FOR STARS IN M25
(Feast's Spectral Types)

Star	CPD No	Sp (Feast)	M_v(Sp)	V_0	$(m-M)_0$	$(B-V)_{0,\,Sp}$	$(B-V)_{obs}$	$E(B-V)$ (Spectra)	$E(B-V)$ (Three Colors)
31	−19°6879	A1 V	+0 75	9 51	8 76	+0 05	0 34	0 29	0 40
50	6881	B6 V	−1 10	6 93	8 03	− 145	25	395	37
51	6882	A0 V:	+0 3	7 75	7 45	00	36	36	50
54	6890	B8 V	−0 5	9 05	9 55	− 09	40	49	50
67	6880	B7 V	−0 8	9 34	10 14	− 13	27	40	37
91	6892	B6 V	−1 1	6 84	7 94	− 145	30	445	42
93	6901	B8 V	−0 5	9 00	9 50	− 09	36	45	46
96	6895	B8 V	−0 5	8 44	8 94	− 09	30	39	42
97	6896	B7 V	−0 8	7 36	8 16	− 13	37	50	48
98	6897	B9 V	0 0	8 75	8 75	− 05	39	44	49
99	6898	B8 V	−0 5	8 39	8 89	− 09	36	45	50
100	6902	B8 V	−0 5	8 57	9 07	− 09	38	47	51
101	6903	B8 V	−0 5	8 92	9 42	− 09	41	50	45
102	6904	B6 V	−1 1	7 69	8 79	− 145	44	495	55
109	6909	A1 V:	+0 75	8 70	7 95	+ 05	43	38	48
120	6891	B8 V	−0 5	9 16	9 66	− 09	39	48	47
142	6905	A1 V	+0 75	7 72	6 98	+ 05	38	33	45
149	6910	A0 V	+0 3	8 86	8 56	00	42	42	52
159	6912	B6 V	−1 1	8 74	9 84	−0 145	0 37	0 515	0 49
Mean					8 76 +0 60 (m e)			0 43 ±0 052 (m e)	0 46 ±0 040 (m e)

TABLE 2*B*

SPECTROSCOPIC MODULI AND REDDENING FOR STARS IN M25
(Wallerstein's Spectral Types)

Star	CPD No	Sp Type	M_v(Sp)	V_0	$(m-M)_0$	$(B-V)_{0,\,Sp}$	$(B-V)_{obs}$	$E(B-V)$ (Spectra)	$E(B-V)$ (Three Colors)
50	−19°6881	B7 III	−3 1	6 93	10 03	−0 13	0 25	0 38	0 37
51	6882	B9 5 V	+0 15	7 75	7 60	− 025	36	385	50
67	6880	B9 V	0 0	9 34	9 34	− 05	27	32	37
91	6892	B6 II–III	−3 7	6 84	10 54	− 145	30	445	42
97	6896	B7 Vn	−0 8	7 36	8 16	− 13	37	50	48
101	6903	B8 5 V	−0 25	8 92	9 17	− 07	41	48	45
102	6904	B8 V	−0 5	7 69	8 19	−0 09	0 44	0 53	0 55
Mean					9 00 ±0 89 (m e)			0 43 ±0 063 (m e)	0 45 ±0 053 (m e)

corrections applied to each star. A fit of this diagram to the age-zero main sequence gives $(m - M)_0 = 8.85$. The determinations from Figures 2 and 3 are not independent because the same stars are used in both, but the distribution of points is different in the two diagrams, so that a comparison is of interest. Figure 4 is the color-magnitude diagram plotted in the corrected co-ordinates of V_0 and $(U - B)_0$. The fit to the age-zero main sequence gives $(m - M)_0 = 8.90$, with an estimated uncertainty of ± 0.2 mag. The mean of our three estimates gives $(m - M)_0 = 8.86$. Johnson (1957) has given $(m - M)_0$

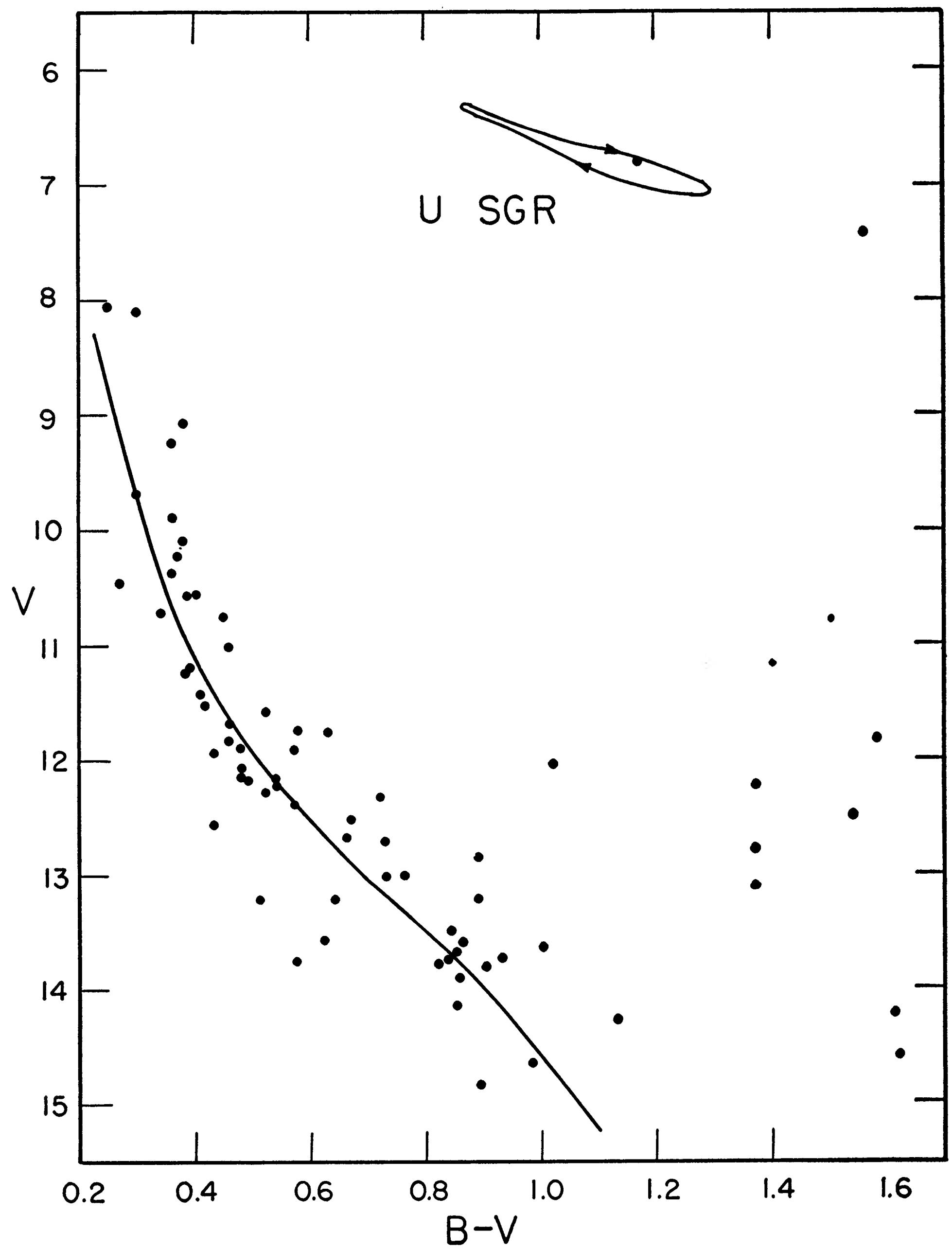

FIG. 2—The color-magnitude diagram for M25 uncorrected for absorption and reddening. The age-zero main sequence is drawn for an apparent modulus of $m-M = 10\ 25$. The data are from Table 1.

= 8.7 for M25 from his independent photometry. A straight mean of the two studies gives $(m - M)_0 = 8.78$, with an estimated uncertainty of less than ± 0.15 mag. This is the value adopted in the next section.

A second method to determine the modulus of M25 is available from the spectroscopic data of Feast (1957) and Wallerstein (1957), where luminosity classes were estimated on the MK classification system. Keenan and Morgan's (1950) calibration of the MK system, together with the magnitudes of Table 1, permit a modulus determination for each star. The data are given in Tables 2*A* and 2*B* for Feast and Wallerstein's classifications separately. The mean modulus of Feast's data is $(m - M)_0 = 8.76$, with a

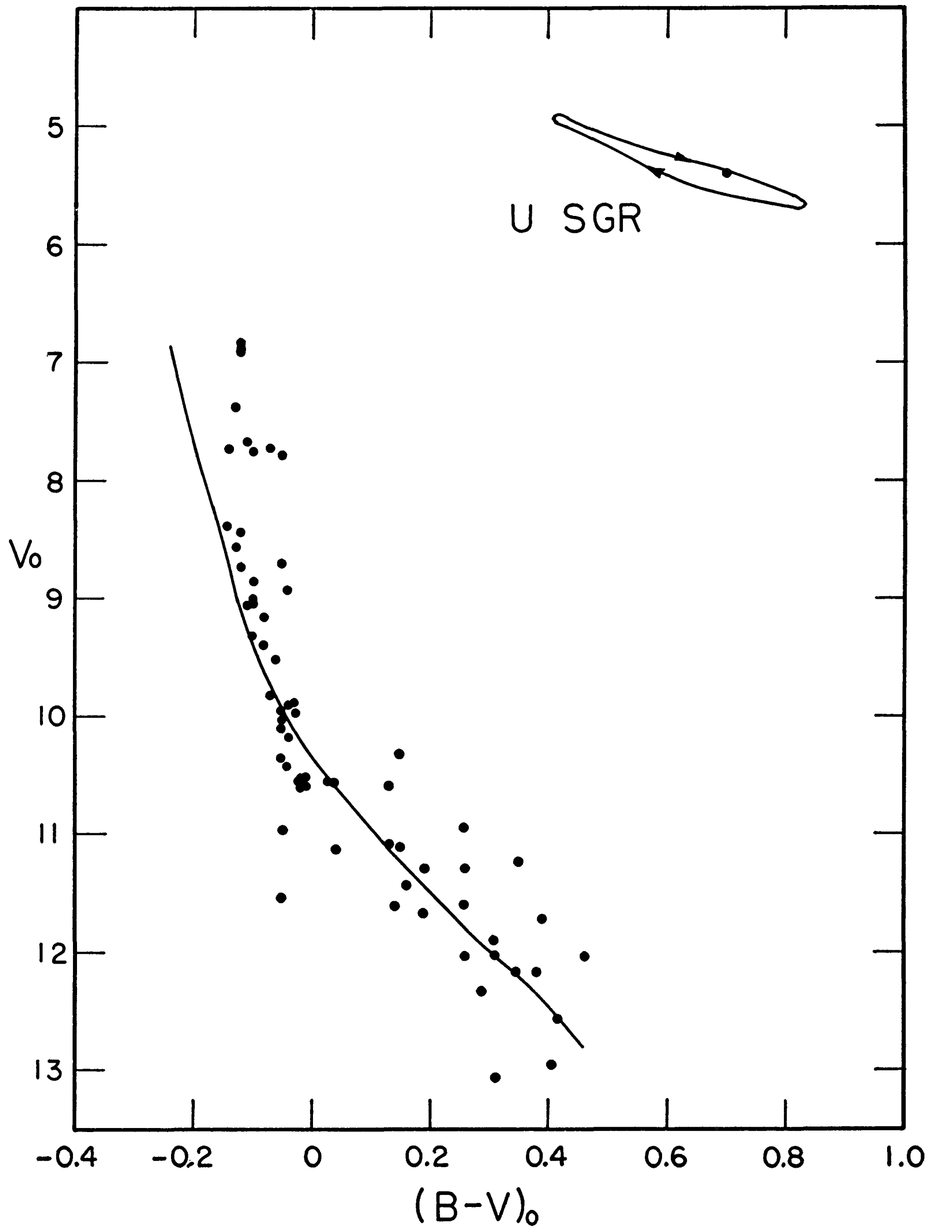

FIG 3—Same as Fig 2, except that each star has been individually corrected for reddening. The age-zero main sequence has been drawn for $(m-M)_0 = 8\ 85$.

mean error for a single star of ± 0.60 mag. The corresponding values for Wallerstein's data are $(m - M)_0 = 9.00 \pm 0.89$ (m.e.). The average of all the data is $(m - M)_0 = 8.82$, with a mean error for a single star of 0.72 mag. The mean error of this average is $\pm 0.72/\sqrt{25} = \pm 0.14$ mag. The value $(m - M)_0 = 8.82 \pm 0.14$ is in excellent agreement with the value already quoted of $(m - M)_0 = 8.78 \pm 0.15$ from the photometric analysis.

IV. THE CEPHEID U SGR

Nineteen separate photoelectric observations in three colors were made of U Sgr. The data are given in Table 3*A*. The phases have been computed from the adopted epoch of maximum light at JD 2436761.956, with a period of 6.744925 days as tabulated in the Russian *Catalogue*. This period fits the present observations. The present observations

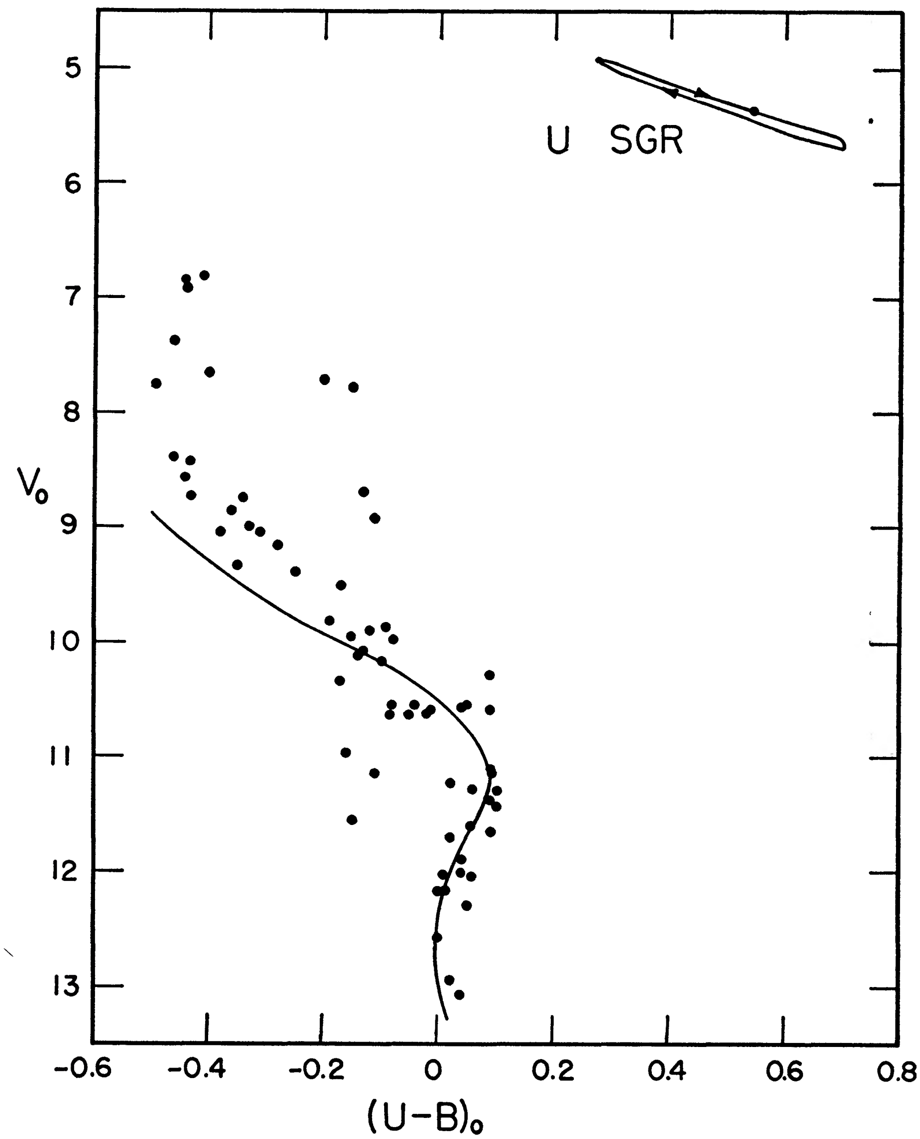

FIG. 4.—The color-magnitude diagram for M25 in V_0 and $(U-B)_0$ co-ordinates. The age-zero main sequence is drawn for a true modulus of $(m-M)_0 = 8\ 90$.

are not adequate to define the light-curve completely because our data miss the maximum phase completely. Eggen has observed U Sgr on his P_{pg}, C_p system, and his data combined with ours define the light- and color-curves with sufficient precision for the present application. The transformation equations used to transform the P_{pg}, C_p values to V and $B-V$ are tabulated by Eggen (1951, eq. [1]; 1955 eqs. [6] and [11]) and reduce to

$$B-V=1.026C_p+0.081\ ,$$

$$V=P_{pg}-1.10C_p+0.24\ .$$

Eggen's transformed data are given in Table 3*B*, where the phases were computed in the same way as before. The light-curves from these data are shown in Figure 5. The blue light-curve compares quite well with that shown by Irwin (1958), except that

TABLE 3*A*

PRESENT PHOTOELECTRIC OBSERVATIONS OF U SGR

JD 2436+	Phase*	V	$B-V$	$U-B$
760 822	0 832	6 98	1 15	0 89
762 790	124	6 51	1 00	0 75
763 701	259	6 70	1 09	0 80
778 719	485	6 86	1 29	0 97
778 811	499	6 93	1 24	0 96
778 836	503	6 91	1 24	0 96
779 689	629	7 05	1 29	0 98
779 778	642	7 04	1 31	0 98
779 824	649	7 06	1 30	1 03
783 710	225	6 71	1 13	0 84
783 758	232	6 71	1 16	0 86
785 669	516	6 92	1 27	0 96
786 692	667	7 09	1 30	1 06
786 742	675	7 07	1 30	1 05
787 673	813	7 00	1 20	0 89
787 731	821	6 97	1 14	0 87
816 666	111	6 48	1 01	0 70
817 675	261	6 69	1 07	0 84
819 651	0 554	6 96	1 27	1 00

* Phase computed from JD 2436761 956 with $P = 6^d.744925$

TABLE 3*B*

EGGEN'S PHOTOELECTRIC OBSERVATIONS OF U SGR

JD 2433+	Phase*	V	$B-V$	JD 2433+	Phase*	V	$B-V$
094 855	0 317	6 69	1 13	145 707	0 856	6 72	0 98
095 840	463	6 89	1 23	146 719	006	6 33	0 84
096 826	609	7 01	1 25	147 726	156	6 54	0 96
098 840	908	6 53	0 93	148 736	306	6 63	1 05
119 785	013	6 34	0 85	151 694	744	6 99	1 14
123 781	606	7 02	1 25	152 696	893	6 58	0 94
125 769	900	6 57	0 93	153 700	042	6 34	0 89
126 764	0 048	6 40	0 89	154 698	0 189	6 54	1 00

* Phase computed from JD 2436761 956 with $P = 6^d.744925$.

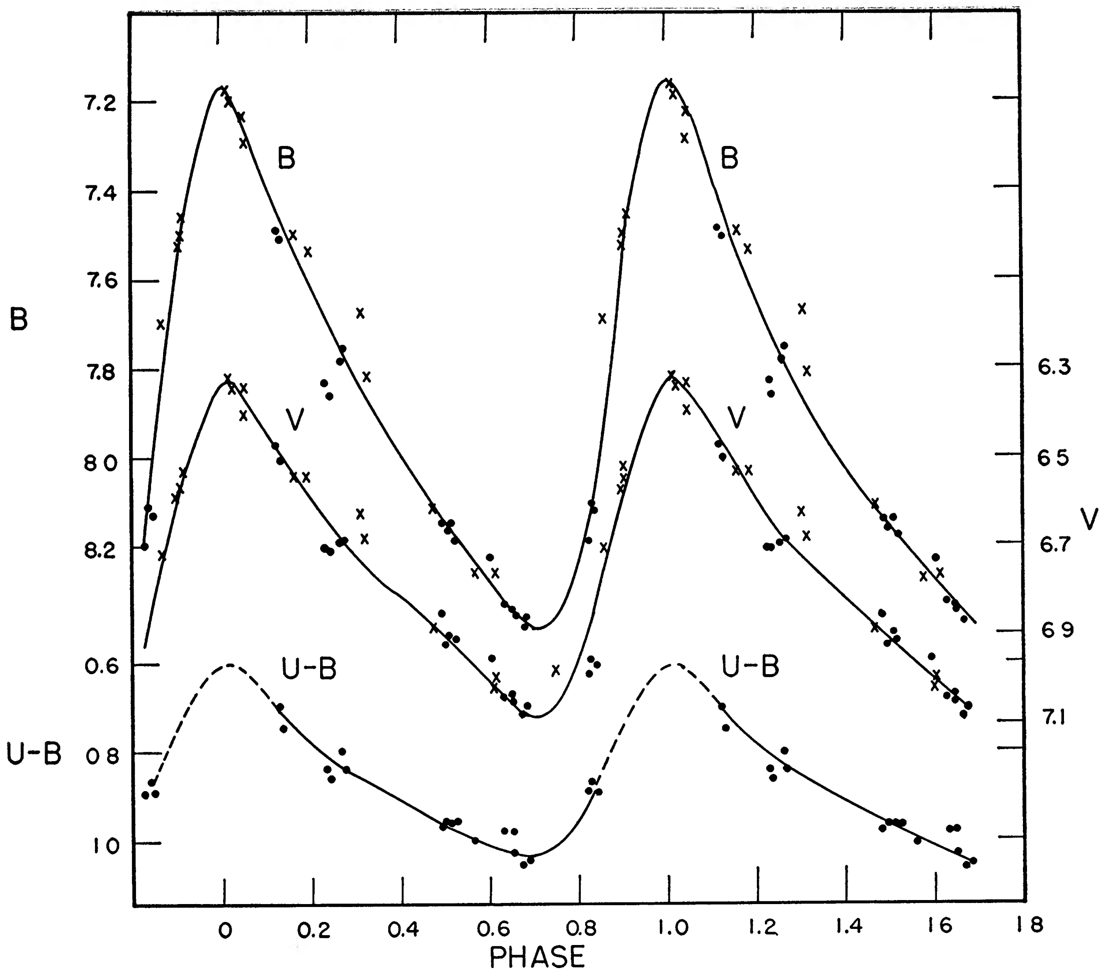

FIG 5.—The light-curves for U Sgr in *B*, *V*, and *U*−*B* The circles are from Table 3*A* The crosses are Eggen's data reduced to the *B*, *V* system from Table 3*B*.

TABLE 4

PHOTOMETRIC PARAMETERS FOR U SGR*

	Max	Min	Mean	Amplitude
V . . .	+6 33	+7 09	+6 73	0 76
$B-V$†	+0 82	+1 30	+1 11	0 48
$U-B$†	+0 61±0 03	+1 04	+0 85±0 03	0 43±0 03
V_0‡ . .	+4 92	+5 68	+5 32	0 76
$(B-V)_0$	+0 35	+0 83	+0 64	0 48
$(U-B)_0$	+0 27±0 03	+0 70	+0 51	0 43±0 03
M_{V_0}§	−3 86	−3 10	−3 46	0 76
M_{B_0}	−3 51	−2 27	−2 87	1 24

* Epoch V(max) = 2436761 96 + 6 744925n (max could occur as much as 0ᵈ3 earlier)

† Tabulated means are $\langle B - V\rangle$ and $\langle U - B\rangle$, $\langle B\rangle - \langle V\rangle$ = 1 06

‡ $E(B - V)$ = 0 47, $E(U - B)$ = 0 34, A_V = 1 41

§ $(m - M)_0$ = 8 78 $\langle B\rangle$ = 7 79, $\langle B_0\rangle$ = 5 91 the bumps on the descending branch are not pronounced in Figure 5. Our points scatter by ± 0.1 mag. near phase 0.25 and may correspond to one of the stand-still points on Irwin's curves. These differences in detail should not affect the derived mean magnitudes of U Sgr by more than a few hundredths of a magnitude.

The curves in Figure 5 were changed into intensity units, planimetered, and the mean intensity converted back into magnitude units, with the result that $\langle V \rangle = 6.73$, $\langle B \rangle = 7.79$, $\langle U \rangle = 8.64$. Other relevant data concerning the light-curves are given in Table 4. The mean absolute magnitudes of U Sgr are $\langle M_{v_0} \rangle = -3.46$ and $\langle M_{B_0} \rangle = -2.87$ if we adopt a true modulus of $(m - M)_0 = 8.78$. Irwin's original value of the luminosity of U Sgr, made it 0.5 mag. discordant from the P-L relation defined by CF Cas, EV Sct, DL Cas, and CV Mon. The new luminosity derived here brings U Sgr into good agreement with the above four.

I should like to thank Dr. John Irwin for supplying a marked chart of M25 for the identification of the stars. It is also a pleasure to thank my wife for useful discussions and for her help in the reduction of the photoelectric data.

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