THE ASTROPHYSICAL JOURNAL, 208:770–775, 1976 September 15

THE CEPHEID SV CRUCIS AND THE CLUSTER RUPRECHT 97

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Received 1975 December 18

ABSTRACT

UBV photometry of Ruprecht 97 is consistent with the assumption that this sparse cluster has $(m - M)_V = 13.7 \pm 0.3$, $E_{B-V} = 0.21 \pm 0.02$, and an age $T \approx 1 \times 10^9$ yr. Cluster membership of SV Cru is ruled out because (1) the cluster is much older than this 7 day Cepheid, (2) the Cepheid is much more distant and more heavily reddened than the cluster, and (3) significant numbers of cluster stars are not observed near the Cepheid, which is located $\sim 110''$ from the cluster center. The period of the Cepheid was found to be $7^d.0044 \pm 0^d.0001$.

Subject headings: clusters: open — stars: Cepheids

I. INTRODUCTION

Attention was first drawn to the possible association of the 7.0 day Cepheid SV Cru and the open cluster Ruprecht 97 [$\alpha(1950) = 11^h55^m22^s$, $\delta(1950) = -62°21'.9$ ($l = 296°.8$, $b = -0°.4$)] by Tsarevsky, Ureche, and Efremov (1966). From *UBV* photometry to $V \approx 14$, Moffat and Vogt (1975) concluded that SV Cru is too bright to be a physical member of the cluster. Furthermore, van den Bergh and Hagen (1975) pointed out that SV Cru is located near the outermost edge of Ruprecht 97. Inspection of Figure 1 (Plate 17) shows that SV Cru is situated $\sim 110''$ northeast of the (poorly defined) center of Ruprecht 97.

We have carried out a program of photoelectric and photographic photometry on the stars within a circular region of radius 46″ (Area I) that is centered on the Cepheid. A similar study has also been made of a region with a radius of 53″ (Area II) that is centered on Ruprecht 97.

II. OBSERVATIONS

Photoelectric *UBV* observations of 31 standard stars obtained with the Cerro Tololo 1.5 m and Yale 1 m telescopes in Ruprecht 97 and near SV Cru are listed in Table 1. The stars in this table are identified in Figure 1. A detailed discussion of the photometric observing procedures is provided in van den Bergh and Harris (1976). Also given in that paper is a comparison of the present photoelectric *UBV* photometry with that of Moffat and Vogt (1975).

The 4 m telescope of the Cerro Tololo Observatory was used at the prime focus on 1975 April 12 (UT) to obtain three 10 min yellow (103a-D + GG495) and three 10 min blue (103a-O + GG385) exposures of Ruprecht 97 in seeing of 1″.0 to 1″.5. Photographic magnitudes of the photoelectric standards, that were read back through the adopted calibration curves, are listed in Table 1. Photographic photometry for all uncrowded stars brighter than the limit of the photoelectric sequence is listed in Table 2 (Area I) and in Table 3 (Area II). The stars in Areas I and II are identified in Figure 2 (Plate 18) and in Figure 3 (Plate 19), respectively.

A comparison between the present photographic and photoelectric observations (which were obtained within one week of each other) is shown in Figure 4. Excluding three badly crowded stars, the standard deviation of the differences between V and V_{pg} is $\sigma_V = 0.07$ mag. For uncrowded stars with $V < 15.0$, $\sigma_{B-V} = 0.10$. These rather large values of σ no doubt resulted because large-scale photographs of the cluster were not available at the time when the photoelectric observations were made. Consequently many of the standard stars, which were selected at the telescope, are slightly crowded. Furthermore, some background sky readings in this rich star field ($b = -0°.4$) may have contained faint ($V < 17$) stars that were not visible in the eyepiece. However, since the number of photoelectric standards used to calibrate the present photographic photometry is large, any systematic errors in the adopted calibrations should be quite small.

III. DISTANCE AND REDDENING OF RUPRECHT 97

A color-color plot for the photoelectric standards of Table 1 is shown in Figure 5. The *UBV* observations are well represented by the intrinsic two-color line (Schmidt-Kaler 1965) for a reddening of $E_{B-V} = 0.21 \pm 0.02$. (The single deviating point is the faintest

* Guest observers 1975, Cerro Tololo Inter-American Observatory. CTIO is operated by AURA, Inc. under contract with the National Science Foundation of the U.S.A.

TABLE 1

PHOTOELECTRIC STANDARDS IN RUPRECHT 97

Star	V	B-V	n	U-B	n	Vpg	(B-V)pg	Tel†	Moffat and Vogt No.
A	9.52	-0.02	2	-0.70	2	9.51	-0.02	1	
B	10.41	1.11	2	0.96	2	10.42	1.11	1	
C	10.51	0.07	2	-0.34	2	10.54	0.11	1	
D*	12.00	1.10	2	0.74	2	11.81	1.01	1, 1.5	
E	12.12	1.23	2	0.93	2	12.08	1.35	1	3
F	12.30	0.40	2	0.24	2	12.31	0.25	1, 1.5	8
G	12.32	0.27	2	0.22	2	12.35	0.09	1	1
H	12.36	0.14	2	0.10	2	12.36	0.09	1, 1.5	
I	12.44	1.38	2	1.03	2	12.42	1.46	1	14
J	12.46	1.24	2	1.05	2	12.40	1.35	1, 1.5	4
K	12.56	0.98	2	0.58	2	12.59	1.06	1, 1.5	20
L	12.82	0.70	2	0.12	2	12.86	0.69	1, 1.5	
M*	12.92	0.68	2	0.15	2	12.62	1.52	1	
N	13.09	0.37	2	0.23	2	13.14	0.24	1	2
O	13.16	0.40	2	0.23	2	12.95	0.59	1, 1.5	15
P	13.20	1.23	1	0.92	1	13.29	1.30	1	28
Q	13.24	0.39	2	0.25	2	13.23	0.47	1, 1.5	5
R	13.26	0.42	1	0.17	1	13.36	0.36	1	16
S	13.64	0.62	2	0.06	2	13.67	0.49	1, 1.5	13
T	14.00	0.48	1	0.28	1	14.08	0.40	1	29
U	14.35	0.46	1	0.26	1	14.37	0.53	1	
V	14.36	0.45	2	0.18	2	14.41	0.31	1, 1.5	
W	14.56	0.84	1	....	0	14.50	0.85	1	
X	14.78	0.39	1	....	0	14.81	0.45	1	
Y	14.94	0.45	1	....	0	14.93	0.52	1	
Z	15.41	1.42	1	....	0	15.25	1.52	1.5	
a	16.11	0.73	1	0.14	1	16.15	0.61	1.5	
b	16.20	0.91	1	-0.17	1	16.18	0.52	1.5	
c	16.29	1.21	1	....	0	16.26	1.20	1.5	
d	16.91	0.58	1	....	0	16.95	0.84	1.5	
e*	16.97	0.74	1	....	0	16.48	0.90	1.5	

† 1 = Yale 1-m telescope, 1.5 = CTIO 1.5-m telescope

* star is very crowded and was not used as a standard

TABLE 2

PHOTOGRAPHIC PHOTOMETRY OF STARS IN RUPRECHT 97 (area I)

Star	V	B-V	Star	V	B-V
1	15.65	0.44	37	14.23	0.75
*2	15.30	0.37	38	16.56	0.32
*3	15.62	0.77	39	16.37	0.50
4	15.35	0.56	40	16.77	0.82
5	15.21	0.68	41	16.76	0.87
*6	15.33	0.55	42	14.97	0.43
7	16.40	0.64	43	16.09	0.61
8	14.43	2.03	44	16.87	0.63
9	15.40	0.50	45	15.30	0.71
10	14.93	0.78	46	16.50	0.49
11	14.37	1.55	*47	16.32	0.98
12	14.06	0.62	48	15.26	0.62
13	15.77	0.82	49	13.81	0.30
14	15.14	0.82	50	14.61	0.96
15	15.73	0.86	51	16.12	0.81
16	16.91	0.62	52	14.94	0.57
17	15.28	0.82	53	16.22	0.90
18	16.45	0.73	54	16.52	0.55
*19	15.63	0.39	55	16.72	1.04
*20	13.01	0.40	*56	14.18	0.53
21	12.23	0.18	*57	14.84	0.28
22	15.69	0.69	58	15.94	1.46
23	15.96	0.86	59	16.49	1.15
24	16.29	0.72	60	16.13	1.02
*25	15.32	0.64	61	16.94	0.56
*26	14.46	0.26	62	15.40	0.68
27	15.80	0.65	63	16.78	0.60
28	15.39	1.57	64	16.90	0.81
29	16.10	0.77	65	17.09	0.61
30	16.49	0.58	66	16.10	0.90
31	16.74	0.57	67	15.51	1.77
32	15.61	0.60	68	16.75	0.71
33	16.46	0.57	69	16.27	0.68
34	16.39	0.73	70	16.19	1.40
35	14.39	0.82	71	16.32	0.76
36	14.99	0.97			

* crowded

TABLE 3

PHOTOGRAPHIC PHOTOMETRY IN AREA II

Star	V	B-V	Star	V	B-V	Star	V	B-V
1	13.80	0.36	*45	14.67	0.38	88	14.97	0.39
2	15.55	0.46	*46	14.83	0.39	89	15.01	0.75
3	15.68	0.39	47	16.66	0.84	90	13.66	0.32
4	15.67	0.44	48	16.49	0.58	91	16.75	0.64
*5	15.20	0.59	49	14.61	0.23	*92	16.53	0.30
*6	16.59	0.88	50	16.58	0.75	*93	16.43	0.56
7	16.38	0.47	51	16.32	0.83	94	15.58	0.32
*8	15.68	0.56	52	15.66	0.44	95	16.51	0.61
9	14.72	0.54	53	12.77	0.69	96	15.76	0.61
10	15.59	0.36	54	15.24	0.25	97	16.68	0.85
11	15.72	0.44	55	13.41	1.16	98	14.77	0.63
*12	14.80	1.54	56	12.63	0.63	99	13.72	0.43
*13	16.96	0.65	57	15.26	0.17	100	14.17	1.75
14	13.91	0.39	58	16.56	1.00	101	16.08	1.23
15	16.62	0.44	59	16.80	0.58	*102	12.26	1.89
*16	15.91	1.55	60	15.09	0.55	*103	14.95	0.92
17	15.09	0.54	61	16.28	0.59	104	16.29	0.65
18	16.22	0.37	62	15.13	0.72	105	15.87	0.60
19	15.96	0.44	63	15.65	0.43	106	16.58	0.92
20	15.94	0.67	64	16.65	0.61	107	14.35	0.89
21	16.17	0.82	65	16.81	0.92	108	16.12	0.39
22	16.39	0.48	66	16.72	0.75	109	15.55	1.04
23	15.36	0.39	67	16.10	0.65	*110	13.79	0.37
24	16.32	0.57	68	15.58	1.93	111	14.69	0.46
25	15.68	0.72	*69	15.75	0.86	112	16.61	0.58
26	15.01	0.87	70	16.53	0.59	*113	14.82	1.83
27	16.32	0.58	71	16.41	0.83	114	15.10	0.76
28	14.42	0.45	72	15.33	0.67	115	15.37	0.85
29	16.20	0.73	*73	15.59	0.45	*116	13.76	1.03
*30	13.33	0.09	74	14.51	0.49	117	15.92	0.60
*31	16.22	0.49	75	14.01	0.70	118	15.10	1.59
32	15.29	0.56	76	13.85	0.68	119	15.97	0.88
33	15.37	1.40	77	14.25	1.35	120	15.66	0.57
34	16.58	0.84	78	15.70	1.07	121	15.73	0.68
35	16.23	0.45	79	14.25	0.29	122	15.13	0.59
*36	13.92	0.34	80	13.52	0.39	123	15.66	1.71
37	15.12	0.40	81	15.90	0.42	124	15.43	0.60
38	16.09	0.44	82	16.24	0.73	125	15.77	0.35
39	15.22	0.51	*83	15.13	0.25	*126	13.70	0.16
40	16.34	0.34	*84	13.84	0.41	127	15.58	0.75
41	15.76	1.42	*85	16.73	0.32	128	13.96	0.72
42	16.32	0.73	*86	14.06	0.09	129	16.07	0.88
43	15.09	1.27	87	17.00	0.48	130	14.99	1.11
44	16.07	0.52						

* crowded

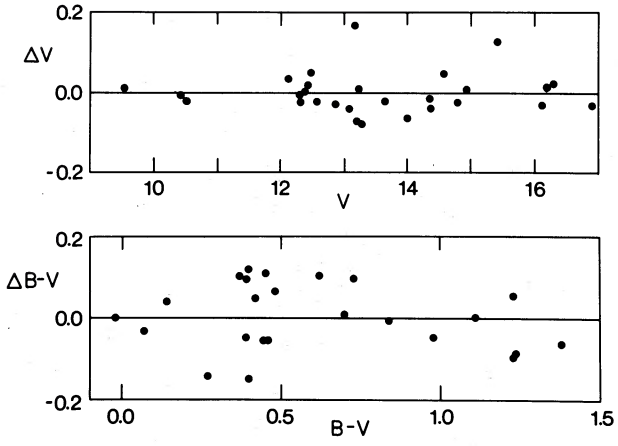

FIG. 4.—Comparison between photographic and photoelectric observations of (uncrowded) standard stars. Differences are in the sense photoelectric minus photographic. $\Delta(B - V)$ values have only been plotted for stars with $V < 15.0$.

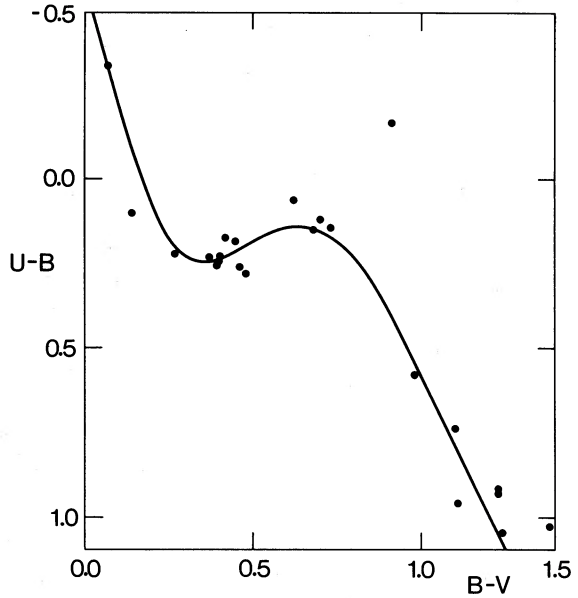

FIG. 5.—Color-color plot for all photoelectric observations. Also shown is the intrinsic $U - B$ versus $B - V$ relation for main sequence stars reddened by $E_{B-V} = 0.21$.

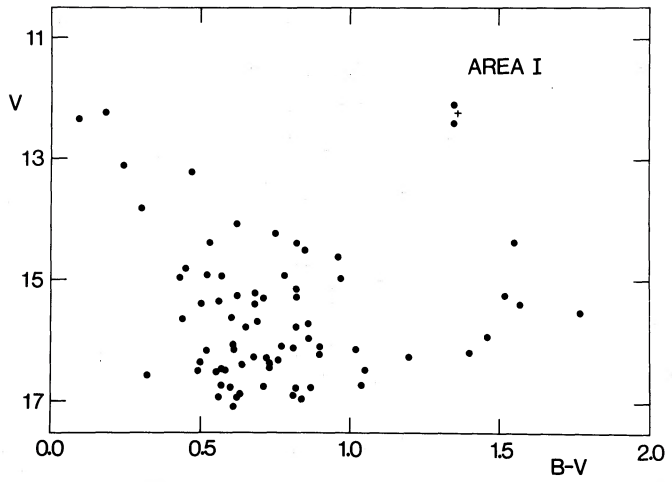

FIG. 6.—Photographic color-magnitude diagram for all uncrowded stars in Area I, which is centered on SV Cru. The variable is marked by a cross.

star for which U was measured). A similar reddening can be found by assuming that all of the UBV standards with $B - V < 0.8$ are main-sequence stars. This is valid for all objects with $8.0 \leqslant (m - M)_0 \leqslant 11.0$ (0.4 kpc $< D <$ 1.6 kpc).

Intercomparison of the color-magnitude diagram for field stars (Fig. 6) with that of stars in the core of Ruprecht 97 (Fig. 7) shows a significant excess of blue stars with $B - V < 0.5$ in the cluster area. The location of these blue stars in the color-magnitude diagram is therefore consistent with the assumption that they constitute the main sequence of a relatively poor intermediate-age cluster. In addition, our photoelectric observations of probable cluster member R and Moffat and Vogt's (1975) UBV photometry of stars II: 1, 14, 36, and 90 are consistent with the assumption that the reddening of Ruprecht 97 itself is also $E_{B-V} = 0.21 \pm 0.02$. We used the evolutionary deviation curve method of Johnson (1960) to derive a distance modulus $(m - M)_V = 13.7 \pm 0.3$. With $A_V/E_{B-V} = 3.3 \pm 0.1$ (Herbst 1975), it follows that $(m - M)_0 = 13.0 \pm 0.3$, corresponding to a distance of 4.0 ± 0.6 kpc.

IV. THE CEPHEID SV CRUCIS

Our observations of SV Cru are listed in Table 4, and the light curve of this Cepheid is plotted in Figure 8 along with earlier observations given by Mitchell *et al.* (1964). The best agreement between the two sets of observations was for a period of $7^d.0044 \pm 0^d.0001$, only slightly different from the revised period of $7^d.004273$ given by Walraven, Muller, and Oosterhoff (1958). We also can rule out the earlier period determination of $7^d.0102$ (Oosterhoff 1928). Table 5 contains the mean parameters for SV Cru, along with the absolute

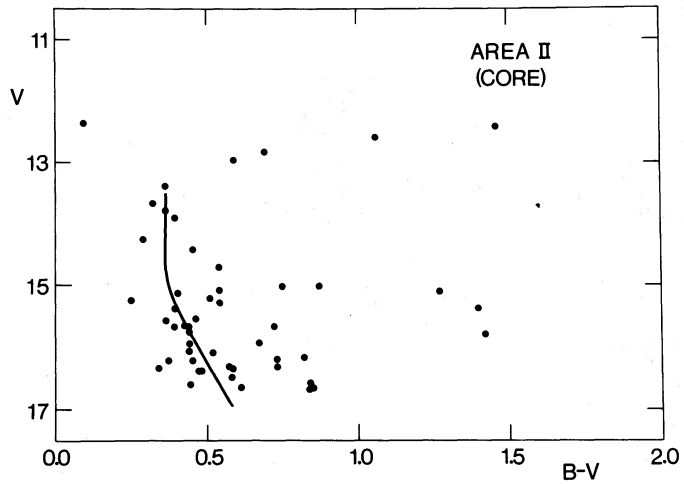

FIG. 7.—Photographic color-magnitude diagram for all uncrowded stars located within the central part of Area II, which contains the core of Ruprecht 97. The adopted cluster main sequence was obtained by applying Johnson's (1960) evolutionary deviation curve on the zero-age main sequence of Schmidt-Kaler (1965).

TABLE 4

PHOTOELECTRIC OBSERVATIONS OF SV CRUCIS

JD (2,420,000.000+)	V	$B-V$	$U-B$	Phase
22508.684.....	12.50	1.57	1.23	0.506
22509.609.....	12.36	1.51	1.17	0.638
22510.699.....	11.76	1.22	0.92	0.794
22511.685.....	11.80	1.29	0.98	0.935
22517.685.....	11.85	1.23	0.84	0.791
22518.640.....	11.86	1.27	0.92	0.928
22519.633.....	12.03	1.41	1.06	0.070
22520.641.....	12.11	1.46	1.20	0.213
22521.642.....	12.27	1.56	1.27	0.356

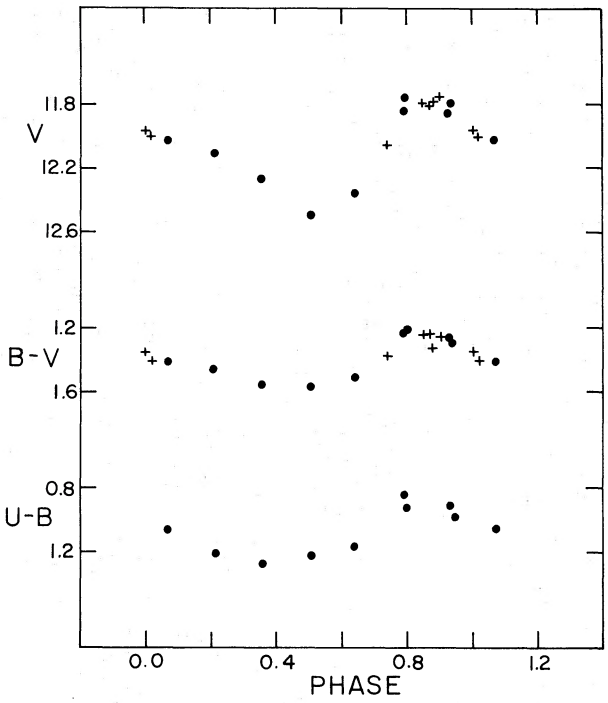

FIG. 8.—Light curves of SV Cru in V, $B-V$, and $U-B$. Circles are recent data from Table 4. Crosses are observations by Mitchell *et al.* (1964).

TABLE 5

PHOTOELECTRIC PARAMETERS OF SV CRUCIS*

$\langle V\rangle$	12.13	$M_{\langle V\rangle}$	$= -1.57$
$\langle B\rangle - \langle V\rangle$	1.39	$(\langle B\rangle - \langle V\rangle)_0$	$= 1.20$
$\langle U\rangle - \langle B\rangle$	$= 1.07$	$(\langle U\rangle - \langle B\rangle)_0$	$= 0.88$

* The symbol $\langle\ \rangle$ denotes an intensity mean over the light curve.

magnitude and intrinsic colors the Cepheid would have *if* it were a cluster member.

V. DISCUSSION

The present observations support the tentative conclusion of Moffat and Vogt (1975) that SV Cru is not associated with the cluster Ruprecht 97. This conclusion appears reasonable from the following arguments:

1. The color-magnitude diagram of Area I (see Fig. 6), which is centered on SV Cru, shows no evidence for an excess of stars on or near the position of the cluster main sequence.

2. With $E_{B-V} = 0.21$, the cluster main-sequence turnoff occurs at $(B-V)_0 = 0.15$. According to Sandage (1963), the corresponding cluster age is $\sim 1 \times 10^9$ yr. This value is inconsistent with Tammann's (1970) age estimate of $\sim 4 \times 10^7$ yr for 7 day Cepheids.

3. From the location of the instability strip given by Sandage and Tammann (1969) (see their Fig. 7) and the period of SV Cru, the Cepheid should have $-3.3 \leqslant M_V \leqslant -4.3$. However, if SV Cru is a member of Ruprecht 97, its absolute magnitude would be -1.57, as given in Table 5.

4. Sandage and Tamman's results (1969) also indicate that a 7 day Cepheid should have an intrinsic color in the range $0.4 \leqslant (\langle B\rangle - \langle V\rangle)_0 \leqslant 0.8$, while dereddening SV Cru by the value derived for Ruprecht 97 gives $(\langle B\rangle - \langle V\rangle)_0 = 1.20$.

The results obtained to date in the present series of investigations of Cepheids in open clusters are summarized in Table 6. In a future paper (van den Bergh 1976) the data on all 10 Cepheids that are now known in clusters will be used to recalibrate the Cepheid Period-Luminosity-Color relation.

We wish to thank Victor Blanco for his hospitality at the Cerro Tololo Observatory and William Harris for assistance with the data reduction. Part of this research was supported by a grant from the National Research Council of Canada.

TABLE 6

SUMMARY OF NEW DATA ON CLUSTER CEPHEIDS

Variable	Status	References
SV Cru.....	Nonmember of Ruprecht 97	Present paper
TW Nor.....	Member of Lyngå 6	van den Bergh and Harris 1976
V367 Sct.....	Member of NGC 6649	Madore and van den Bergh 1975 van den Bergh and Madore 1976
CS Vel.....	Member of Ruprecht 79	Harris and van den Bergh 1976

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PLATE 17

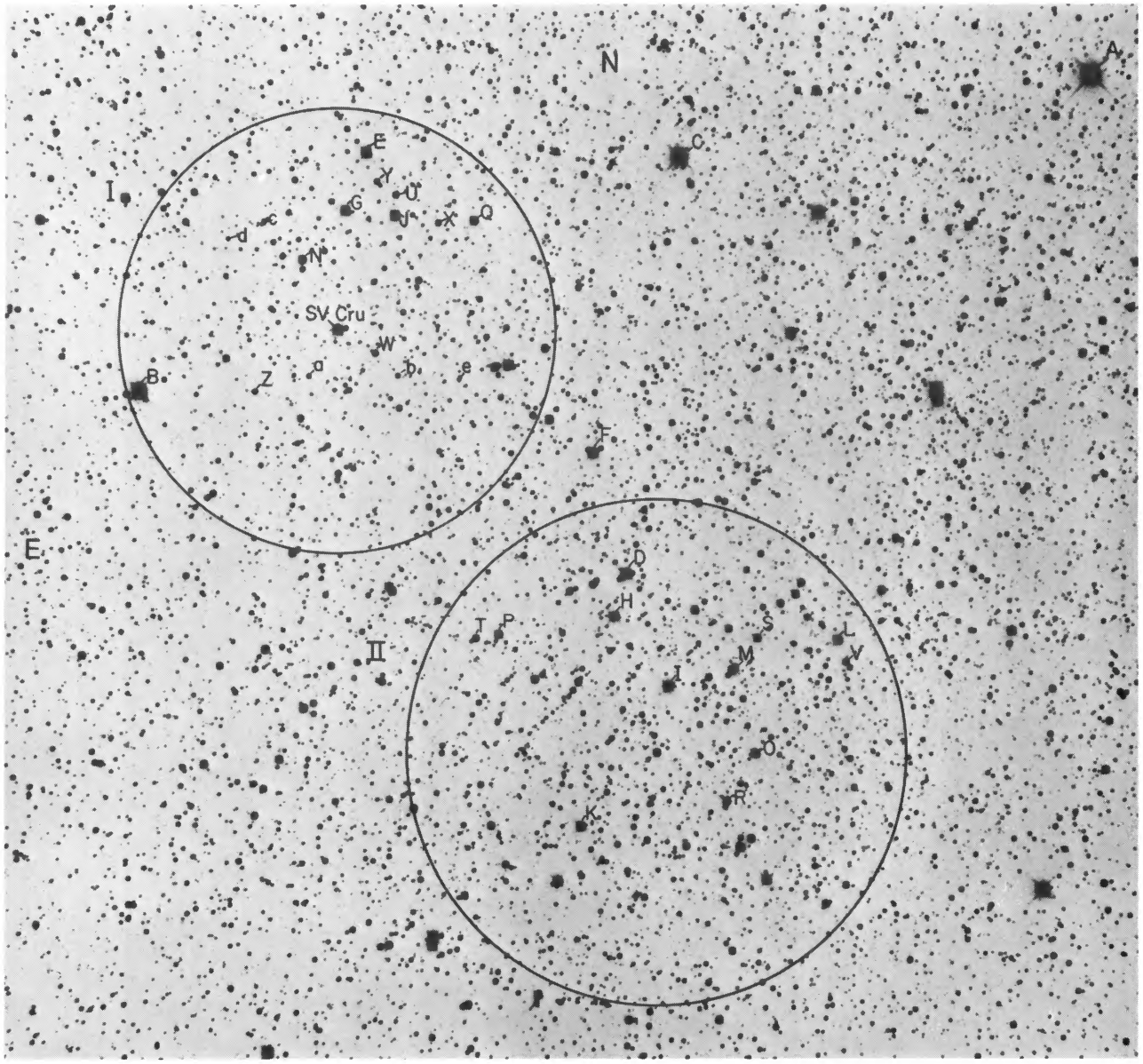

FIG. 1.—Identification chart for photoelectric standards in Ruprecht 97 and near SV Cru. This chart was prepared from a blue plate obtained with the CTIO 4 m telescope.

VAN DEN BERGH *et al.* (*see* page 770)

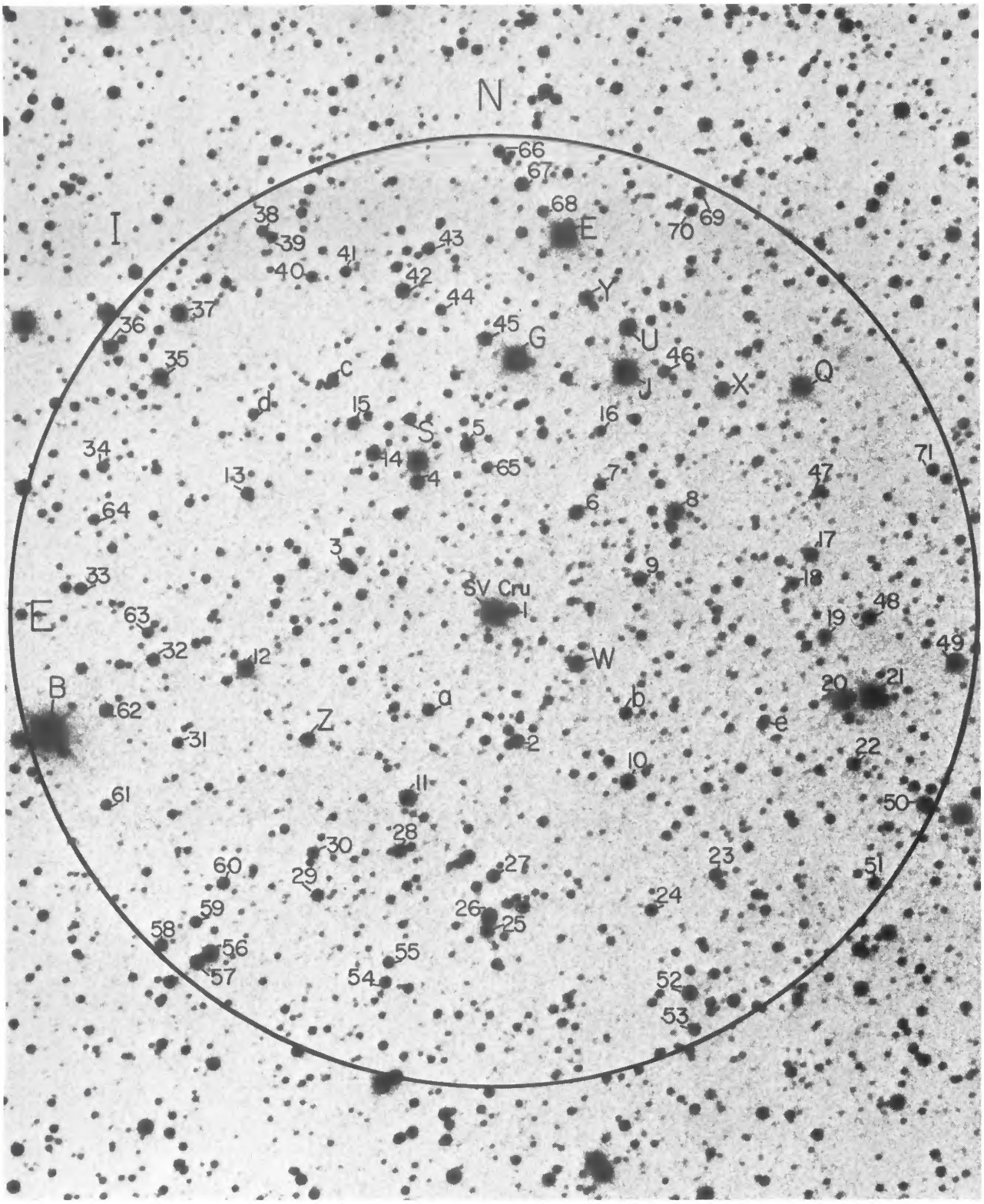

FIG. 2.—Identification chart for photographic photometry in Area I, which is centered on the Cepheid SV Cru and has a radius of 46″.

VAN DEN BERGH *et al.* (*see* page 770)

PLATE 19

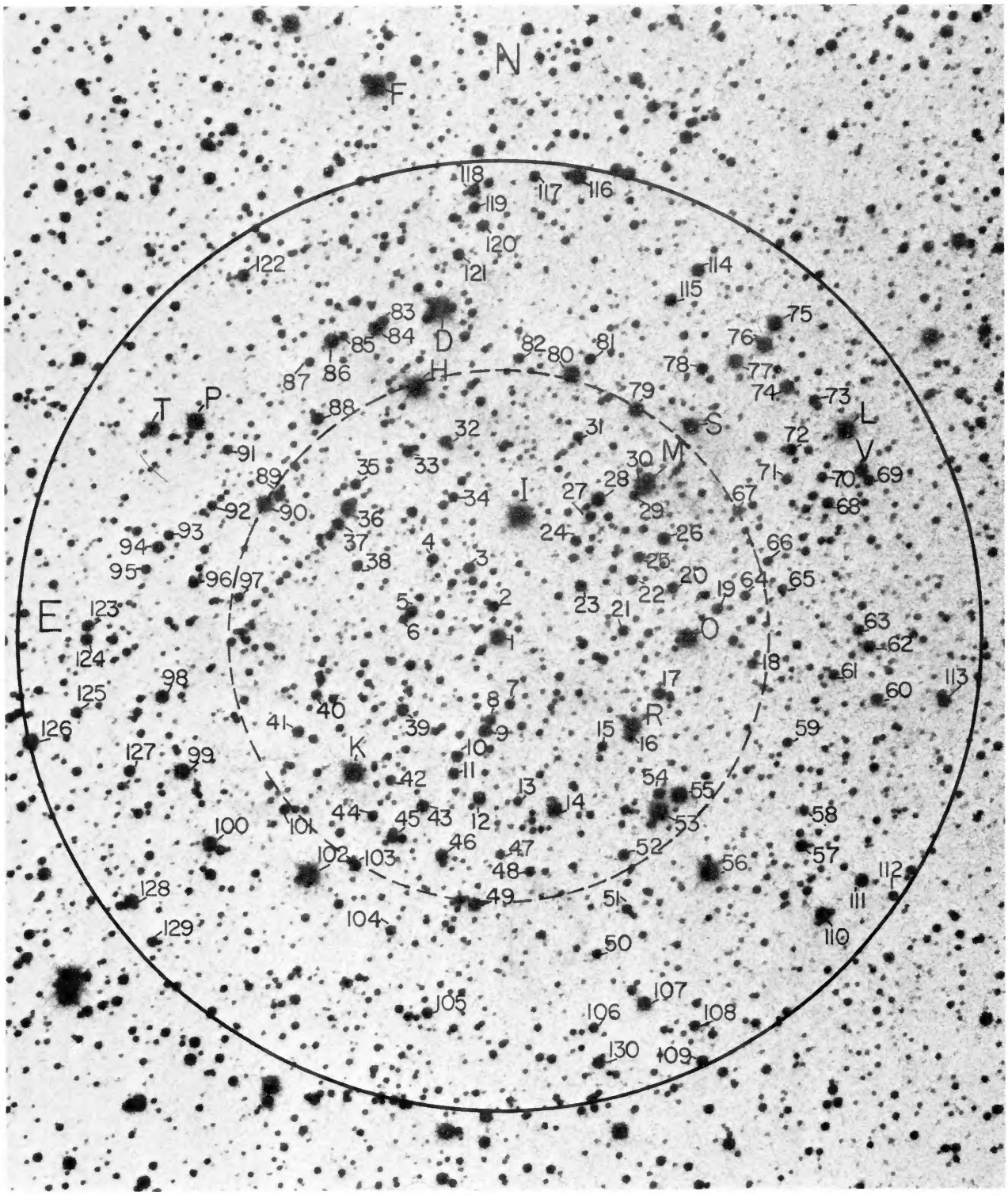

FIG. 3.—Identification chart for photographic photometry in Area II. This area has a radius of 53″. The dashed circle, which encloses the *core* of the cluster Ruprecht 97, has a radius of 30″.

VAN DEN BERGH *et al.* (*see* page 770)