THE ASTROPHYSICAL JOURNAL, 191:63–65, 1974 July 1

A PRELIMINARY PHOTOELECTRIC SEQUENCE IN THE GALAXY M33 OF THE LOCAL GROUP

ALLAN SANDAGE
Hale Observatories, Carnegie Institution of Washington, California Institute of Technology
AND
HAROLD L. JOHNSON*
Applied Physics Laboratory, Centro de Investigación Científica, Baja California; and Instituto de Astronomía, Universidad Nacional de México
Received 1973 December 20

ABSTRACT

Forty-seven stars in two areas of the nearby galaxy M33 were measured photoelectrically between 1954 and 1959 using the Mount Wilson and Palomar reflectors. The sequence ranges from $8.0 \leq V \leq 21.3$, $8.9 \leq B \leq 21.5$ and has been photographically smoothed fainter than $V \simeq 17.5$ by Dixon from measurements of eight 5-meter Hale reflector plates. The sequence, while not definitive, is sufficiently accurate for future work on the stellar content of this highly resolved galaxy.

The galactic foreground reddening lies in the range $0.02 \leq E(B - V) \leq 0.09$. Eight likely members of M33 are among the sequence stars.

Subject headings: galaxies, individual — photometry

I. INTRODUCTION

Messier 33 (center: $\alpha_{1950} = 1^h31^m2^s.9$; $\delta_{1950} = +30°24'10''$) is the nearest late-type Sc galaxy. It is a member of the Local Group, and is highly resolved into all the constituents expected in a normal Population I aggregate (luminous stars, H II regions, Cepheids, clusters, novae, etc.).

Hubble (1926) discovered Cepheid variables in the system and made a preliminary study of the stellar content using plates taken with the Mount Wilson reflectors. His magnitude sequences were based primarily on photographic transfers to Selected Area 45 (a few to SA 21), which lies only half a degree west of the galaxy's center. But the sequences were not published, and it is difficult now to correct them for the scale and zero-point errors that are known to occur fainter than $m_{pg} \simeq 17$.

Improvement of the distance determination to M33 is an important current problem, and correction of the Cepheid photometry is clearly fundamental. To this end, a new study of the stellar content of M33, including the brightest blue and red stars, was begun in 1953. As a first step, we began in 1954 to determine a skeleton photoelectric sequence in several parts of the galaxy, first with the Hooker 2.5-meter Mount Wilson reflector, and later with the Hale 5-meter Palomar telescope. The observations were completed in 1959, and have not been published heretofore. However, the sequence has proved useful for a number of projects by others, and is presented here as a base upon which to eventually build a definitive photometric system in this galaxy.

* The work was done while at the Lowell Observatory, Flagstaff, Arizona.

II. THE OBSERVATIONS

A bright sequence $12.6 < V < 17.6$ was determined south of NGC 604 ($\alpha_{1950} = 1^h31^m44^s$; $\delta_{1950} = +30°31'50''$) in the north-following interarm region. Its purpose is to eventually obtain photometry of the ~30 stars in the central cluster of the NGC 604 H II region. The general area of the sequence is outlined in figure 1 (plate 11), and is shown in detail in figure 2 (plate 12). The stars identified there are listed in table 1. Stars 15, 16, 19, and Var 2 are from the preliminary photographic photometry of Hubble and Sandage (1953), figs. 1 and 4, and table 1) in the "central" region of the galaxy.

The fainter sequence ($8.0 < V < 21.3$), whose purpose is to reach as faint as conveniently possible in the "clear" south-preceding interarm region, is identified in figure 3 (plate 13), with the results listed in table 2.

TABLE 1

PHOTOELECTRIC SEQUENCE IN THE NE QUADRANT IDENTIFIED IN FIGURE 2

Name	V	$B - V$	$U - B$	Telescope (inches)	Obs.
A..........	16.35	1.01	...	100	S
B..........	15.52	0.92	+0.56	100	S
C..........	15.56	0.60	−0.04	200	S
D..........	15.99	1.52:	1.03	100, 200	S
E..........	17.07	1.57	...	100	S
F..........	16.47	1.18	...	100	S
G..........	12.66	0.51	−0.02	100	S
H..........	17.58	1.64	2.17	200	S
L..........	17.05	0.47	0.16	100	S
X..........	15.07	0.66	0.10	200	S
W..........	16.79	0.29	0.11	200	S
15..........	16.82	0.63	0.04	200	S
16..........	17.01	0.27	−0.42	100	S
19..........	16.08	1.60	...	200	S

The region, outlined in figure 1, is very far from the center (star 30 is at $\alpha_{1950} = 1^h29^m39^s.3$; $\delta_{1950} = +30°19'15''$; star A2 at $\alpha_{1950} = 1^h29^m45^s.5$, $\delta_{1950} = +30°13'49''$), and is generally free from the photometric pandemonium of the spiral arms. Only the background sheet of the Population II is present as underlying contamination; but because the gradient of this sheet is small, it proved possible to do moderately accurate photometry in the area. We were especially aware of the obvious contamination problems when the candidate stars were chosen, and were careful to measure immediately adjacent sky positions where the background appeared similar to that at the star position on long-exposure photographs.

Blind offsets were made at the Mount Wilson and Palomar reflectors fainter than $V \simeq 18$ and $V \simeq 19$, respectively, and both pulse-counting and DC techniques were used to record the data.

We consider the photometry to be a reconnaissance effort. The accuracy for some stars fainter than $V \simeq 19$ may not be individually better than $\sim \pm 0.15$ mag, or in particularly difficult cases of crowding or high background an occasional random error of ~ 0.3 mag may occur. (The straight photon statistics, however, were always carried to a point where the formal rms error was always less than ~ 0.08 mag.)

Data on the errors come from comparison of the photoelectric results with the photographically smoothed values, also listed in table 2. These results by Dixon are based on the average of four prime-focus Hale reflector plates in each of the two colors measured during the course of his work on the spiral pattern in this galaxy (Dixon 1971). His photographic smoothing was done with a Ross-like fixed-aperture photometer which, to good approximation, gives systematically accurate magnitudes from photographic plates in the presence of variable background (Ross 1936; Dixon 1970).

Comparison of the two magnitude systems in table 2 shows agreement in the zero point of the smoothed sequence to within 0.02 mag (forced), and rms deviation of 0.04 mag in V for V brighter than 20, and $\sigma = 0.13$ mag for fainter stars. Three stars in V (16, 23, and 39) and two in B (16 and 39) have residuals larger than 0.3 mag. The general comparison seems quite satisfactory to $V \simeq 21$, $B \simeq 21.3$ for many problems concerning the stellar content of M33.

But again, we caution that the photometry is preliminary, and is based on very few duplicate measurements. For example, there are five stars between $V = 13$ and $V = 17$ in common with the separate work of Johnson and of Sandage. We agree only to

TABLE 2

Photoelectric Sequence in SW Interarm Region Identified in Figure 3 including Dixon's Photographically Smoothed Values

Name	V	$B-V$	$U-B$	n	Obs.	B_{pg}	V_{pg}
1	13.36	+0.46	−0.03	8	JS	...	...
2	13.99	+0.83	+0.48	4	JS	...	...
3	17.17	+0.77	+0.23	1	J	17.89	17.10
4	20.04	+0.45	−0.17	1	J	20.65	20.03
5	20.63	+0.28	...	1	J	21.00	20.84
6	21.31	+0.24	...	1	S	21.27	...
7	17.82	+1.25	+1.35:	1	J	19.06	17.95
8	20.01	+0.16	+0.50	1	J	19.94	19.98
9	20.70	−0.14	−0.94	1	S	20.70	20.76
10	17.41	+0.56	+0.21	1	J	18.04	17.45
12	19.94	+0.05	−0.95:	2	JS	20.12	20.17
13	17.67	+0.20	−0.13	2	J	17.85	17.66
14* = A17	17.01:	+0.64	+0.25	4	JS	17.63	16.81
15 = A12	16.08	+0.57	−0.02	7	JS	...	...
16	20.23	+1.17	...	1	S	20.89	20.54
18	17.56	+0.52	−0.11	1	J	18.08	17.44
19†	19.70	−0.03	+0.05	1	J	...	...
20	19.31	+0.67	−0.14	1	J	20.02	19.30
22	20.60	−0.03	−0.68	1	S	20.76	20.57
23	20.74	−0.13	−0.31	1	J	20.63	20.41
26	14.24	+0.69	+0.12	1	J	...	...
27	20.75	+0.86	...	1	J	...	...
28	8.00	+1.03	+0.89	Std	J	BD+29°256	
30	11.80	+0.53	−0.03	4	JS	...	...
31	13.26	+0.64	+0.10	2	J	...	...
39	20.84	+0.21	−0.68	1	S	20.50	20.23
A2	13.64	+0.89	+0.50	1	S	...	...
A4	14.12	+0.95	+0.63	1	S	...	...
A7	14.86	+0.88	+0.44	1	S	...	...
A10	15.60	+0.50	+0.03	1	S	...	...
A11	15.80	+0.56	+0.04	1	S	...	...
A14	16.37	+0.67	+0.09	1	S	...	...
A16	16.94	+0.64	+0.09	1	S	...	...

* May be variable. † V may be 19.20.

$\langle V_J - V_S \rangle = -0.06 \pm 0.02$, $\Delta(B - V)_{J-S} = -0.05 \pm 0.03$, $\langle B_J - B_S \rangle = -0.11 \pm 0.03$, and $\Delta(U - B)_{J-S} = +0.02 \pm 0.11$. This is a gross disagreement for a definitive sequence, but we have permitted it to remain unexplained and untested because it is insignificant for most problems. The differences, if real, concern only the zero point, and not the scale. But clearly, the stars listed in tables 1 and 2 should not be used as secondary standards for other photoelectric photometry until the sequences are strengthened.

III. COMPARISON WITH THE SEQUENCE OF HUBBLE AND SANDAGE

We have measured stars in common with the sequence published by Hubble and Sandage (HS 1953) to test their transfers to SA 68. The stars prefixed with *A* in table 2 are the same as identified in HS figure 4 and in figure 3 here. There are 12 stars in common, including numbers 15, 16, and 19 of their "central region" (HS fig. 4). Comparison shows $\langle B - m_{pg} \rangle = 0.21$ mag with $\sigma = 0.14$ mag, and $\langle V_{pe} - V_{HS} \rangle = -0.08 \pm 0.06$ mag for nine common stars in region A. The magnitudes of HS are, then, not grossly in error. The principal change in the absolute magnitudes of the supergiant blue irregular variables (in their table 3) is caused by the increased distance modulus to M33 of $(m - M)_{AB} = 24.74$ (Sandage and Tammann 1974) compared with 23.8 used by HS.

IV. THE REDDENING AND A FEW INTERESTING STARS

Most of the stars in tables 1 and 2 are in the galactic foreground. The two-color diagram reveals a general reddening of $E(B - V) = 0.09 \pm 0.02$ based on the 14 stars brighter than $V = 18$ with $0.6 \leq B - V \leq 1.0$. Most of the stars are from table 1. If the difference $\Delta(B - V)_{J-S}$ of -0.05 were due entirely to a color zero-point error by Sandage, the reddening from table 1 would be $E(B - V) \simeq 0.02$. Hence, the true value from our data lies in the range $0.02 \leq E(B - V) \leq 0.09$.

Independent values of the reddening are $E(B - V) = 0.03 \pm 0.02$ by McClure and Racine (1969), and $E(B - V) = 0.08 \pm 0.03$ by Schmidt-Kahler (1967). Therefore, no closer decision than our limits is possible from any of the available data.

It seems clear from the two-color diagram that stars 9, 12, 19, 22, 39, and probably 23 in table 2 are blue supergiant members of M33. Star H (table 1) is clearly a red supergiant (note the very red $U - B$ color). Star 7 is a less certain giant member, while D must be a red dwarf in our own Galaxy. As before, we caution that $U - B$ values for stars fainter than $V \simeq 18$ should be treated with appropriate caution, and therefore that the precise position in the two-color diagram of the six blue members of M33 is not well determined.

REFERENCES

Dixon, M. E. 1970, *Observatory*, **90**, 57.
———. 1971, *Ap. J.*, **164**, 411.
Hubble, E. 1926, *Ap. J.*, **63**, 236.
Hubble, E., and Sandage, A. 1953, *Ap. J.*, **118**, 353.
McClure, R. D., and Racine, R. 1969, *A.J.*, **74**, 1000.
Ross, F. E. 1936, *Ap. J.*, **84**, 241.
Sandage, A., and Tammann, G. A. 1974, *Ap. J.*, **190**, 525 (Paper I).
Schmidt-Kaler, Th. 1967, *A.J.*, **72**, 526.

Harold L. Johnson
Av. Gastelum No. 898, Ensenada, Baja California, Mexico

Allan Sandage
813 Santa Barbara Street, Pasadena, California 91101

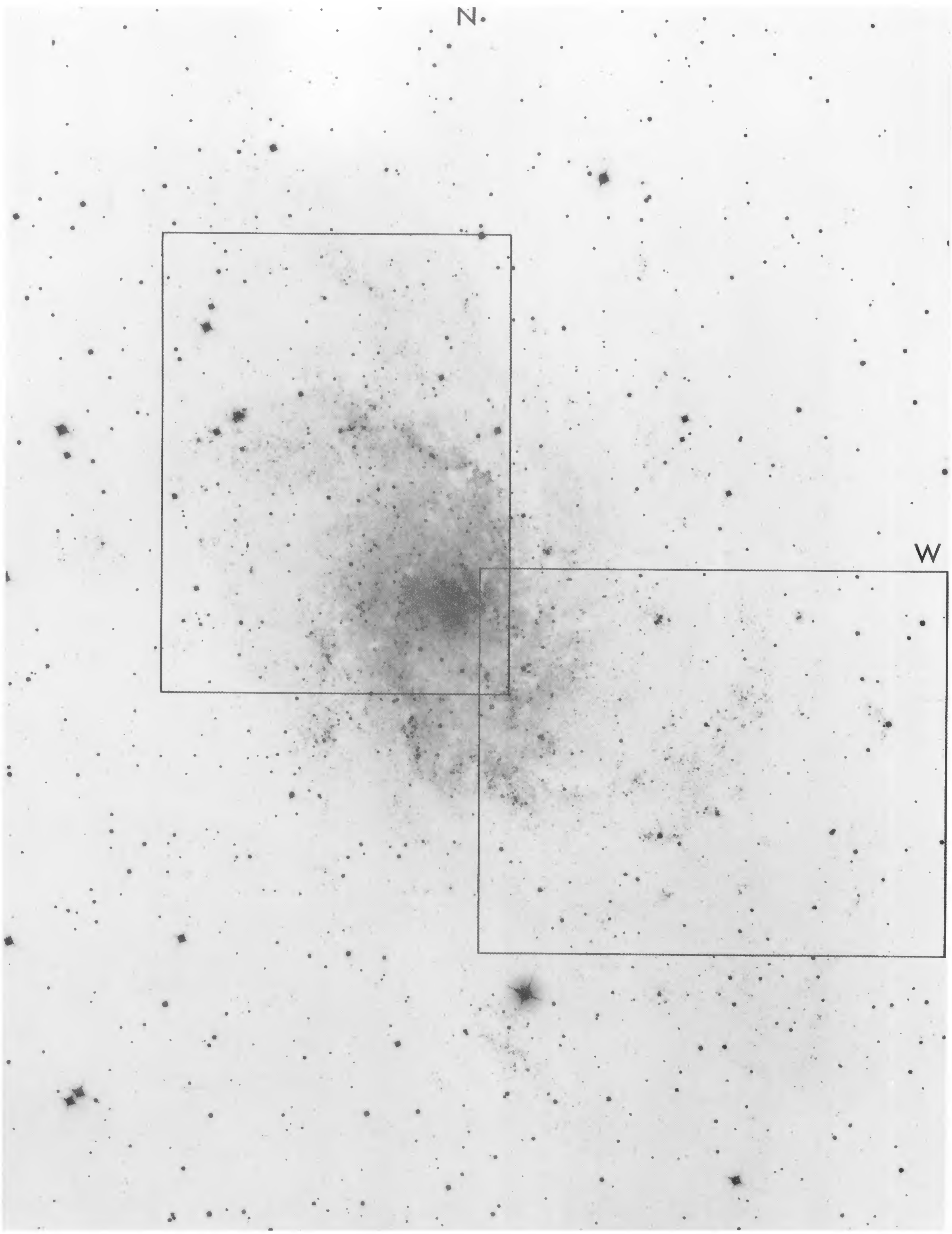

FIG. 1.—General location chart for the two sequence areas in M33 that are shown in more detail in figs. 2 and 3. Reproduced from a Newtonian-focus plate taken with the Mount Wilson 2.5-m Hooker telescope on 103aD emulsion with yellow Plexiglas filter, with the mirror stopped to 1.5 meters to increase the coma-free field.

SANDAGE AND JOHNSON (*see* page 63)

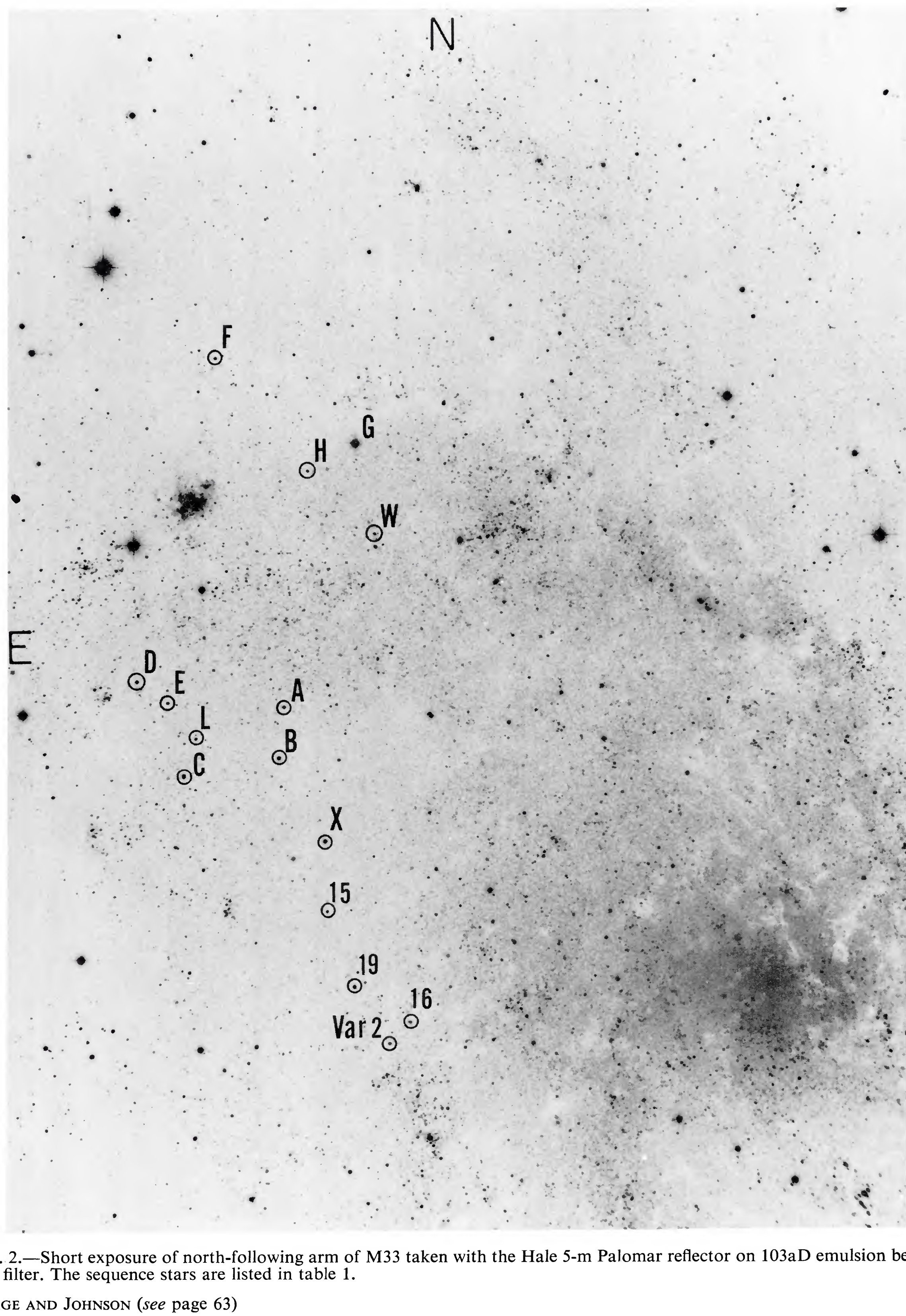

FIG. 2.—Short exposure of north-following arm of M33 taken with the Hale 5-m Palomar reflector on 103aD emulsion behind a GG11 filter. The sequence stars are listed in table 1.

SANDAGE AND JOHNSON (*see* page 63)

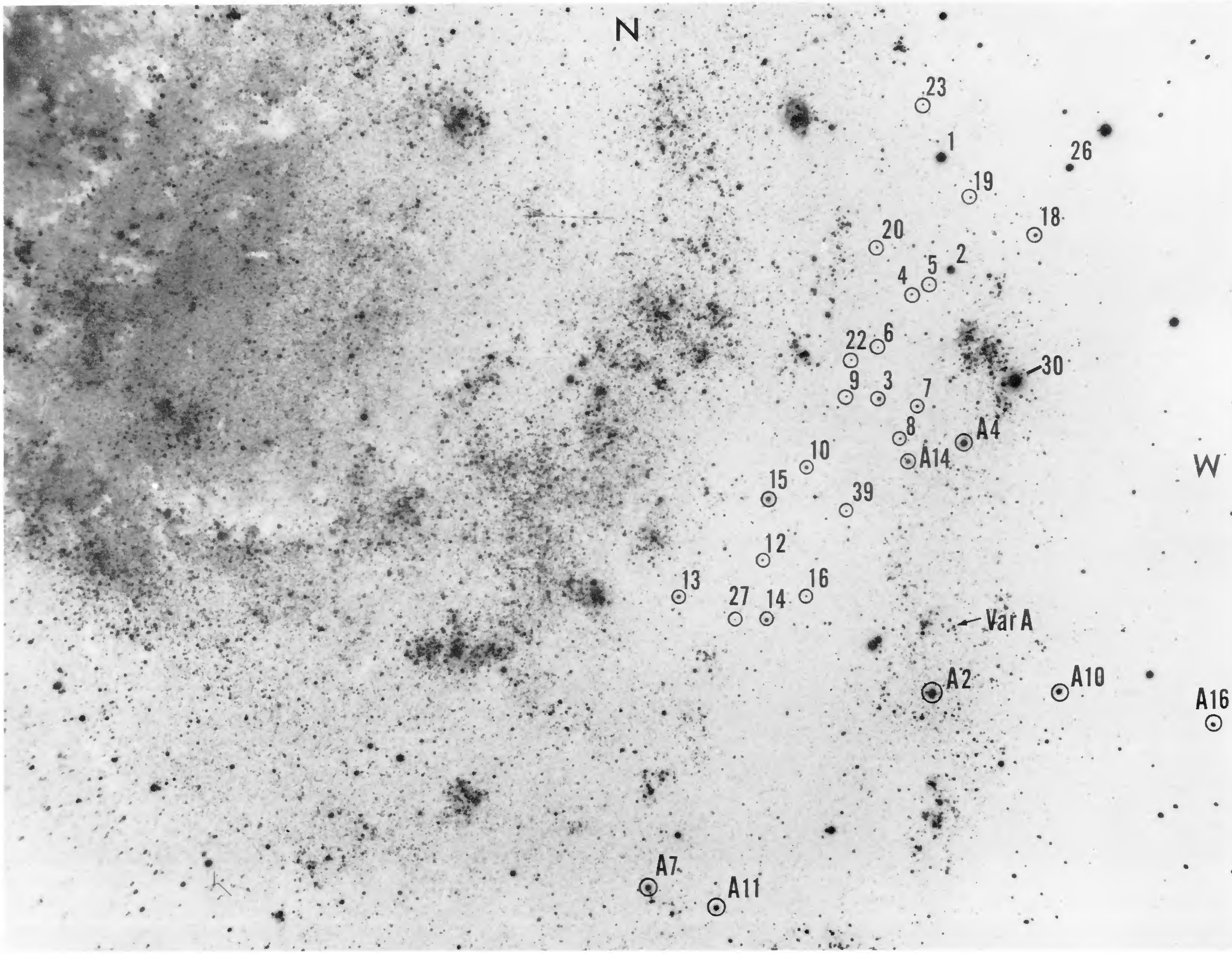

FIG. 3.—Long exposure blue plate (103aO + GG13) of south-preceding arm and interarm regions of M33. The sequence stars of table 2 are identified. Stars prefixed by A are also identified in fig. 3 of Hubble and Sandage (1953).

SANDAGE AND JOHNSON (*see* page 63)