STUDIES OF THE LARGE MAGELLANIC CLOUD. I. THE RED GLOBULAR CLUSTERS

PAUL W. HODGE
Harvard College Observatory
Received September 28, 1959

ABSTRACT

An area of 125 square degrees centered on the Large Magellanic Cloud has been searched in two colors for globular clusters. Many of the previously reported globulars were found to be not genuine, and a number of new globulars were identified. A total of 35 clusters in the area searched are true globulars, as defined by their color-magnitude diagrams These appear to be distributed preferentially in the eastern part of the Cloud. Some clusters have abnormally faint giant branches.

I. INTRODUCTION

Shapley and his collaborators (see Gascoigne 1954) have given numerous lists of globular clusters in the Large Magellanic Cloud. Clusters were identified as globular from their appearance on blue plates. However, as Shapley pointed out, some clusters that appeared globular were classified spectrographically as A types by Miss Cannon. Photoelectric measurements made by Gascoigne and Kron (1953) of the integrated colors of the clusters demonstrated the existence of two groups—red, or normal, globulars, and "blue globulars." The most conspicuous of the latter group, NGC 1866, which was always listed previously as a globular, has been found by Sandage and Arp (1957) to have a color-magnitude diagram similar to that of the galactic cluster M11. Investigations by the author of some of the other "blue globulars" have provided further evidence that these objects are more closely related to the open clusters of our Galaxy than to the globular clusters.

The discovery by Thackeray and Wesselink (1953) of RR Lyrae variables in clusters of both Clouds demonstrated that population II clusters do exist in the Clouds and suggested that the red globulars measured by Gascoigne and Kron are probably true globulars as we know them in our Galaxy. The red globulars are of primary interest both from the point of view of distance scale problems and from that of questions of stellar evolution. The need for a catalogue of true globulars in the Large Magellanic Cloud prompted the writer to take special plates for this purpose while he was carrying out photometry in the Cloud at the Boyden Observatory, South Africa, in 1958–1959.

II. THE OBSERVATIONS

The ADH Baker-Schmidt telescope was used to make a series of 40 plates covering the Large Magellanic Cloud. The correcting lens was diaphragmed to 24 inches to give a field 3° in diameter free of vignetting. Plates in B and V of the U, B, V system of Johnson and Morgan (1953) were obtained by using the standard plate-filter combinations of Kodak 103*a*-O plus a 2-mm Schott GG 13 filter for B and Kodak 103*a*-D plus a 2-mm Schott GG 11 filter for V. Exposures were 30 minutes, giving a nearly uniform limiting magnitude of 18.5 in each color.

An area of sky centered on the position $\alpha = 5^h20^m$, $\delta = -69°.1$ (1950) and extending

about 10° in the north-south direction and 12°.5 in the east-west direction was covered by 20 plates in each color. The corners of this rectangular area have the positions:

(1950) α	δ
4^h21^m	$-63°.6$
6^h21^m	$-63°.6$
3^h57^m	$-73°.5$
6^h42^m	$-73°.5$

This area includes the main part of the Cloud as determined by star counts (McCuskey 1935) but does not include the distant extensions reported by de Vaucouleurs (1955). The search is believed to be complete within the area covered, but globular clusters at even greater distances may well exist.

TABLE 1

GLOBULAR CLUSTERS IN THE LARGE MAGELLANIC CLOUD

Cluster	α(1960)	δ(1960)	Diam	Concentration Class	Description
NGC 1651	4^h37^m8	−70°40′	1′.1	IX	Moderately rich
NGC 1652	4 38 4	−68 45	0 4	VII	Poor
NGC 1751	4 54 5	−69 53	1 0	VIII	Moderately poor
NGC 1754	4 54 6	−70 31	0 6	III	Rich
NGC 1783	4 59 0	−66 03	2 1	VI	Rich
NGC 1786	4 59 2	−67 48	0 6	II	Rich
NGC 1795	5 00 2	−69 51	0 8	IX	Moderately poor
NGC 1806	5 02 3	−68 03	1 5	V	Rich
NGC 1835	5 05 4	−69 27	0 9	III	Rich
NGC 1846	5 07 6	−67 30	1 3	VII	Rich
Anon 1	5 16 2	−68 58	1 1	VIII	Moderately rich
NGC 1898	5 17 0	−69 42	0 8	V	Moderately rich
Anon 2	5 18 2	−69 42	0 8	VI	Moderately rich
NGC 1917	5 19 3	−69 02	0 7	V	Moderately rich
NGC 1953	5 25 7	−68 52	0 6	II	Rich
NGC 1978	5 28 5	−66 16	1 9	V	Rich
Anon 3	5 29 4	−68 20	0 6	VII	Poor
Anon 4	5 31 7	−64 44	0 7	X	Moderately poor
Anon 5	5 40 5	−72 16	0 4	VI	Poor
Anon 6	5 43 0	−71 40	1 0	VII	Moderately poor
NGC 2108	5 44 2	−69 12	0 7	IX	Moderately poor
NGC 2121	5 48 7	−71 29	1 5	X	Rich
Anon 7	5 49 7	−67 45	1 0	X	Moderately poor
Anon 8	5 54 2	−67 48	1 1	XI	Moderately poor
Anon 9	5 56 7	−70 18	1 2	XI	Moderately rich
NGC 2154	5 57 7	−67 16	0 9	VII	Moderately rich
Anon 10	5 57 8	−67 06	1 0	XI	Moderately poor
NGC 2155	5 58 4	−65 28	0 9	VIII	Moderately poor
NGC 2173	5 58 8	−72 59	0 9	VII	Moderately rich
NGC 2162	6 00 2	−63 43	0 6	IX	Poor
NGC 2209	6 09 5	−73 50	1 3	XI	Moderately rich
NGC 2213	6 11 2	−71 31	0 8	IV	Moderately rich
NGC 2210	6 11 8	−69 07	1 0	III	Moderately rich
Anon 11	6 14 5	−69 50	1 4	VIII	Rich
NGC 2231	6 20 8	−67 30	0 8	IX	Moderately rich

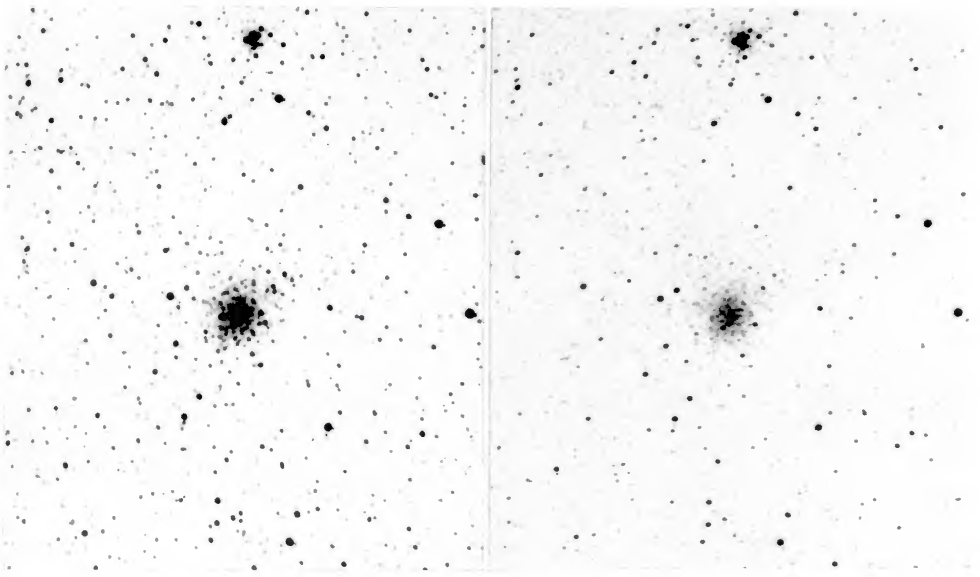

FIG. 1.—The globular cluster NGC 1846 enlarged from the yellow (*left*) and the blue (*right*) ADH plates.

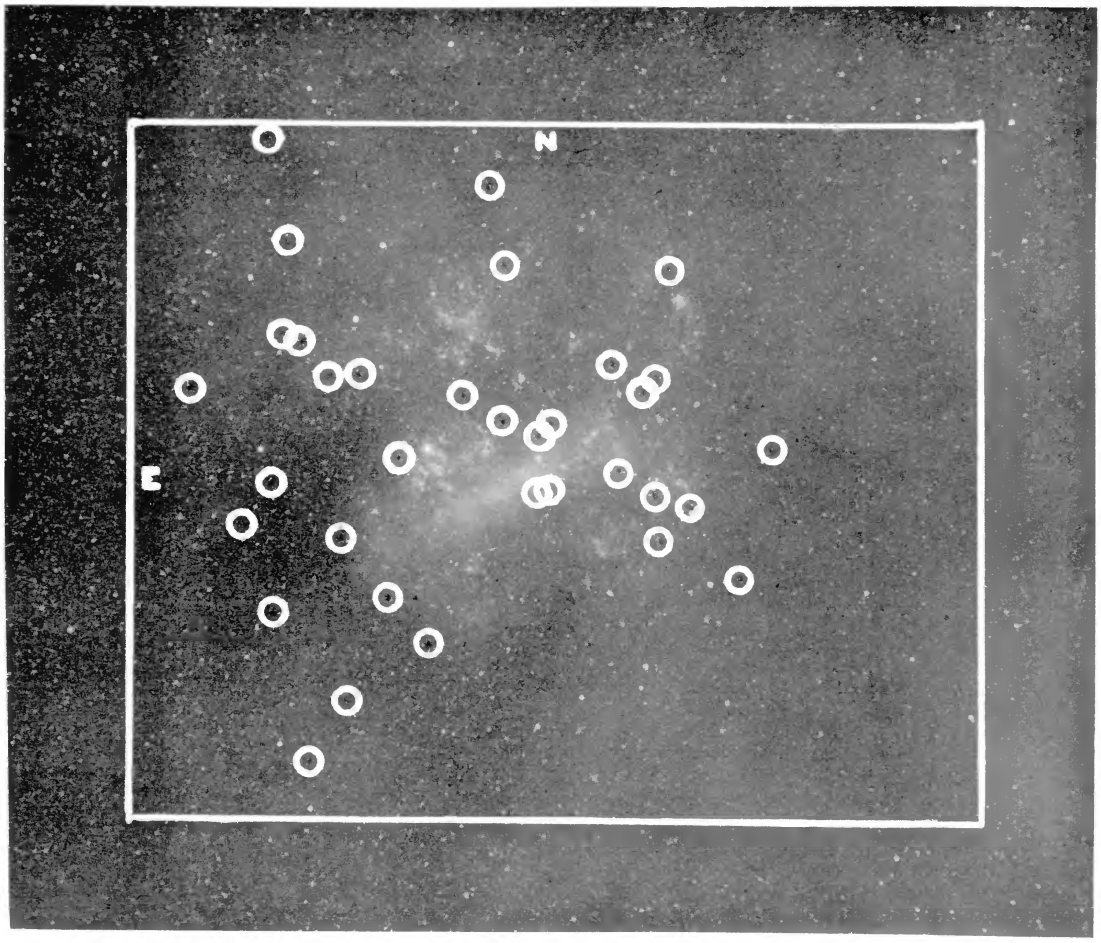

FIG. 2.—The distribution of red globular clusters of the Large Magellanic Cloud. The borders of the area searched are shown on this patrol camera plate.

1960ApJ...131..351H

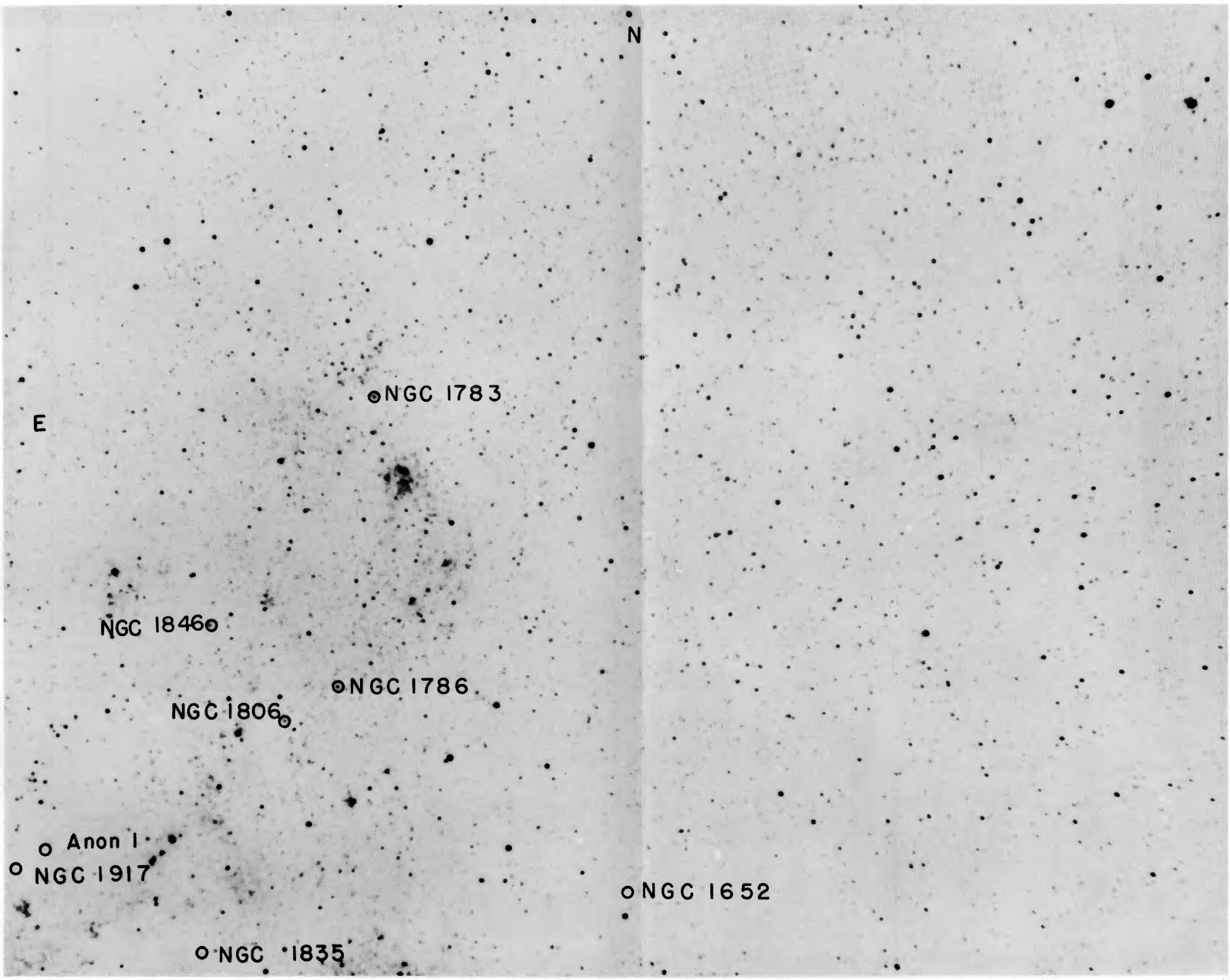

FIG. 3*a*.—The northwest quarter of the Large Magellanic Cloud enlarged from a patrol camera plate. The red globular clusters are identified

1960ApJ...131..351H

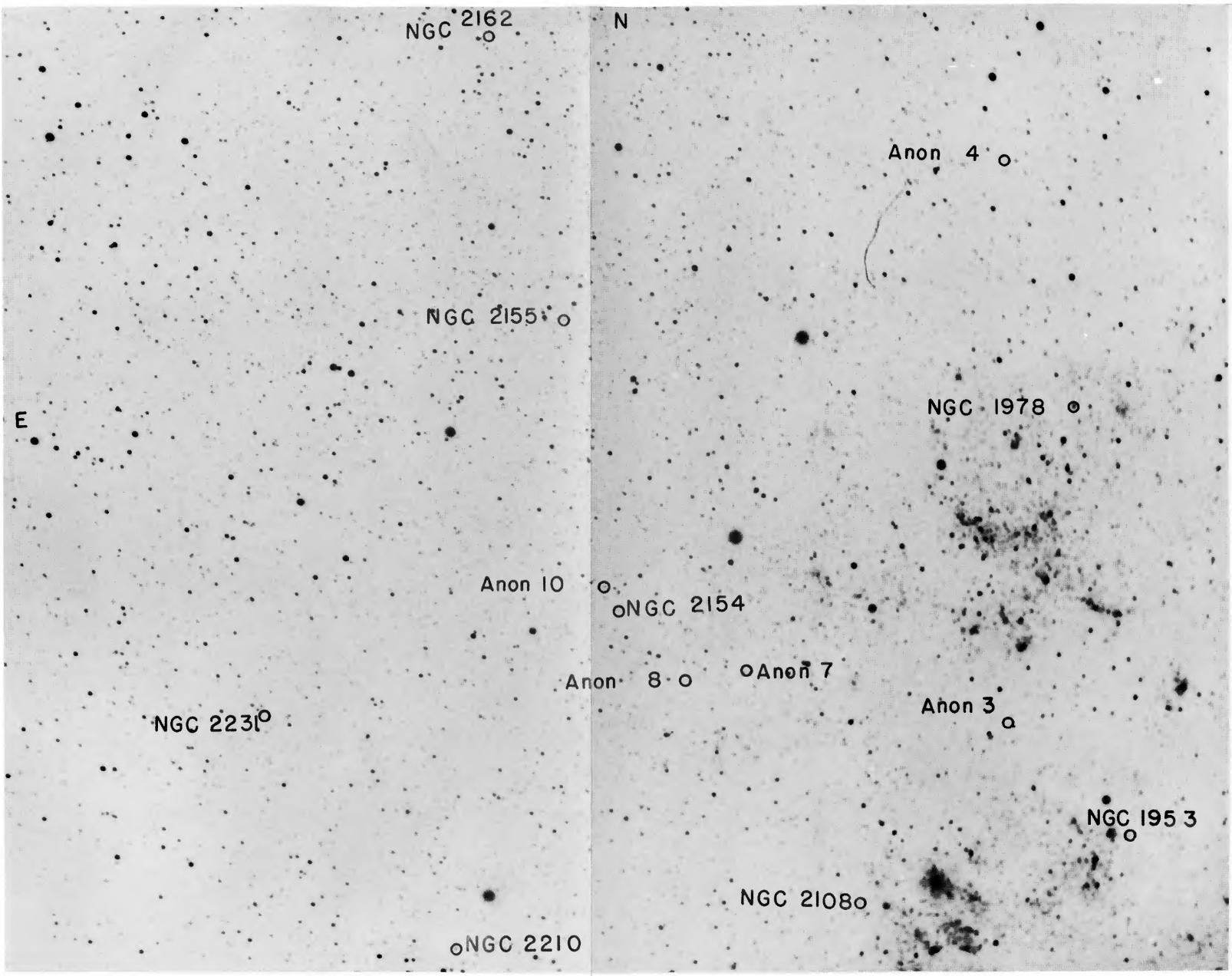

FIG. 3*b*.—The northeast quarter of the Cloud with the red globulars identified

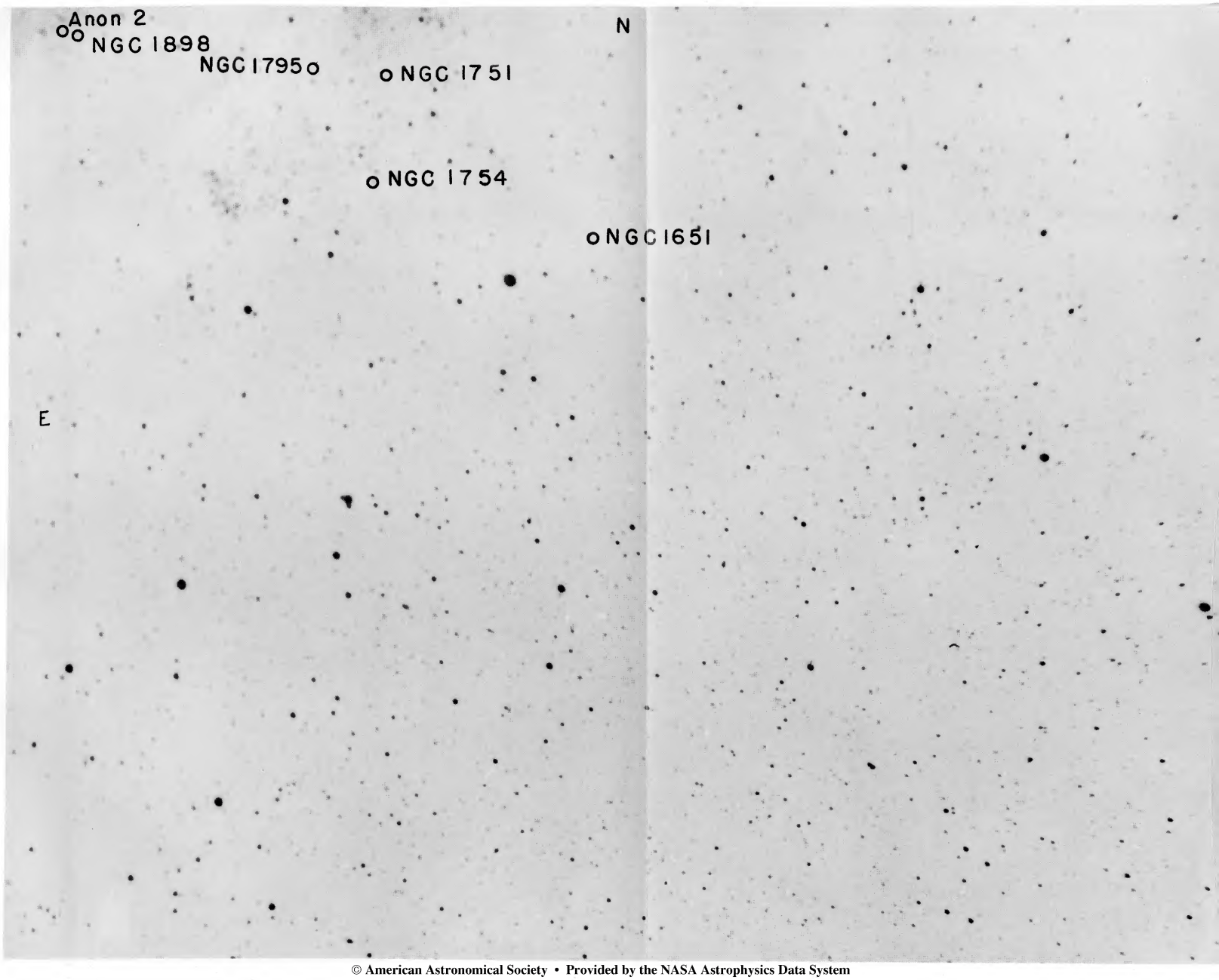

FIG. 3*c*.—The southwest quarter of the Cloud with the red globulars identified

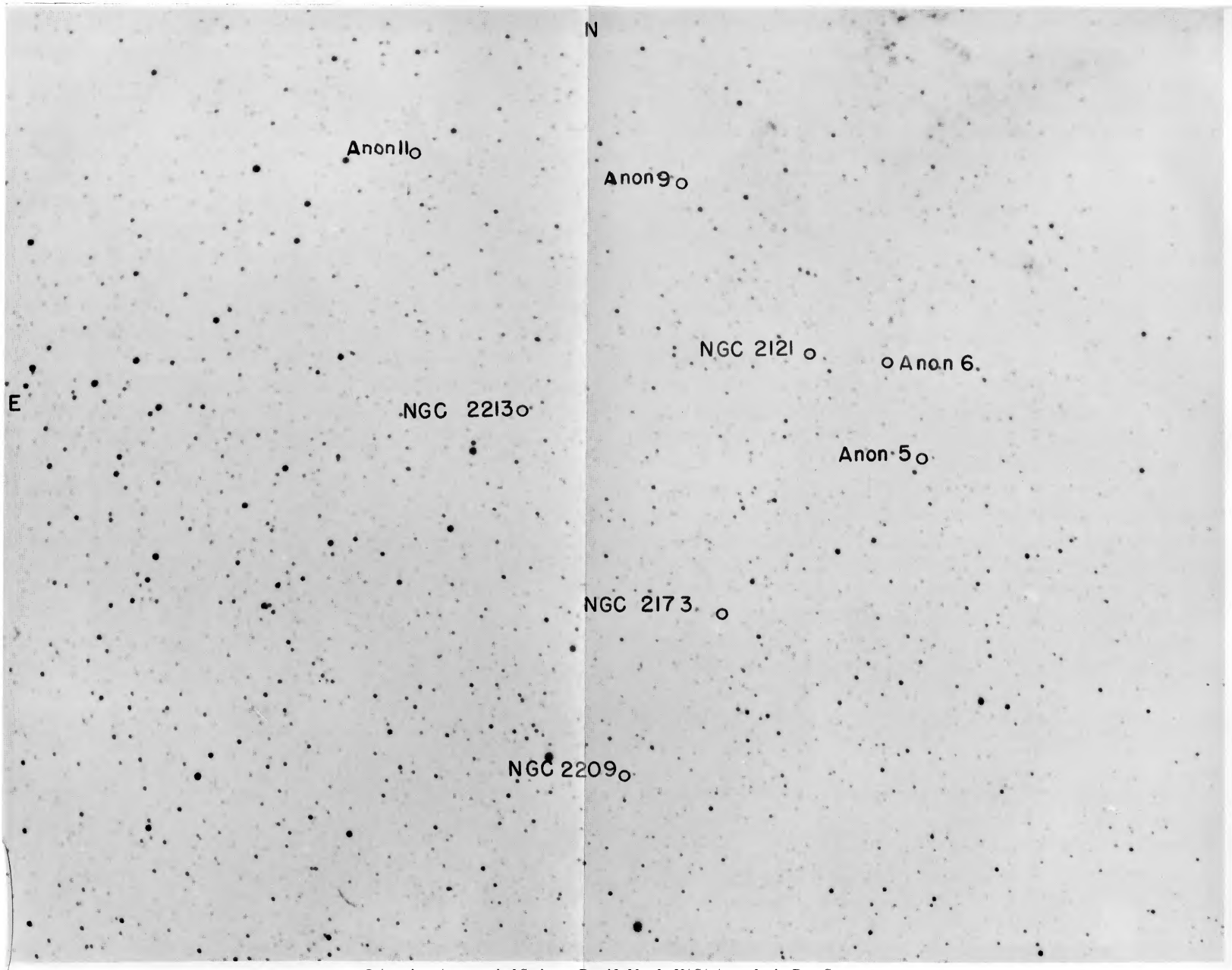

FIG. 3*d*.—The southeast quarter of the Cloud with the red globulars identified

TABLE 2

POSSIBLE GLOBULARS IN THE LARGE MAGELLANIC CLOUD

Cluster	α(1960)	δ(1960)	Reason Doubtful
NGC 1868	$5^h 14^m.3$	−64° 00′	Not on blue plate
Anon 14	5 29 0	−73 39	Defective on yellow plate
IC 2136	5 39 0	−74 48	Not on yellow plate

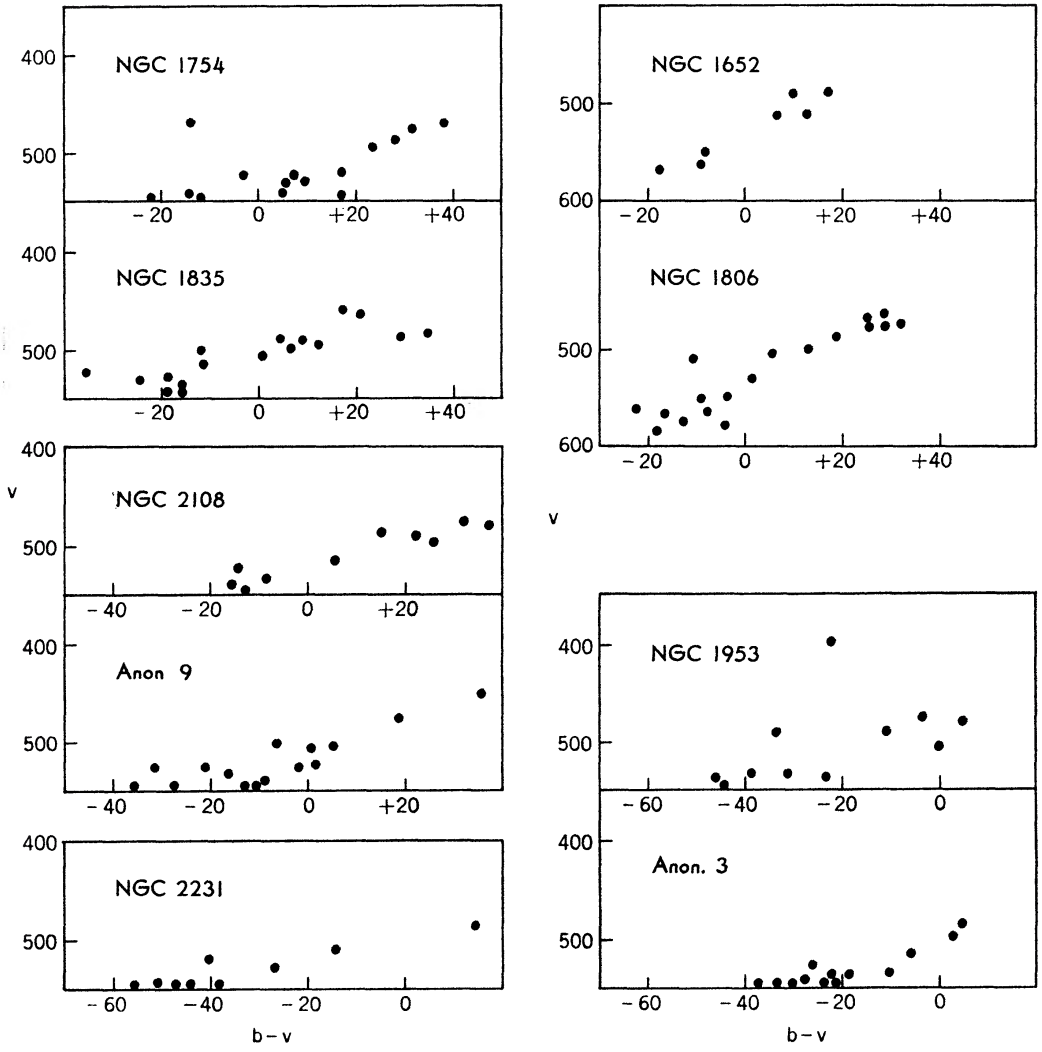

FIG. 4.—Uncalibrated color-magnitude diagrams for 9 globular clusters. Ordinates are measurements on the yellow plates, abscissa are blue measures minus yellow measures. Diagrams which are boxed together are for clusters measured on the same plates They may therefore be intercompared.

The globular clusters were identified by the available part of their color-magnitude diagrams. The plate limit was near absolute magnitude zero, the distance modulus of the Cloud being about 19, according to studies of the novae (Schmidt 1957). Since the upper part of the normal globular-cluster color-magnitude diagram is nearly horizontal when plotted in terms of B and $B - V$, the blue plates would be expected to show a cluster of nearly equally bright stars just above the plate limit. Because of the fairly steep giant branch that occurs when V is plotted against $B - V$, however, the yellow plate would be expected to show a cluster of stars with magnitudes varying from that of the plate limit to 2 or 3 mag. above plate limit. None of the known or expected color-magnitude diagrams for galactic clusters, such as those collected by Sandage (1958), would appear at all similar to this on such plates. Thus a simple comparison of the plates by a blink microscope should segregate immediately the globular clusters from the galactic-type clusters of the Cloud, provided that the latter have the characteristics observed so far in the open clusters of our Galaxy.

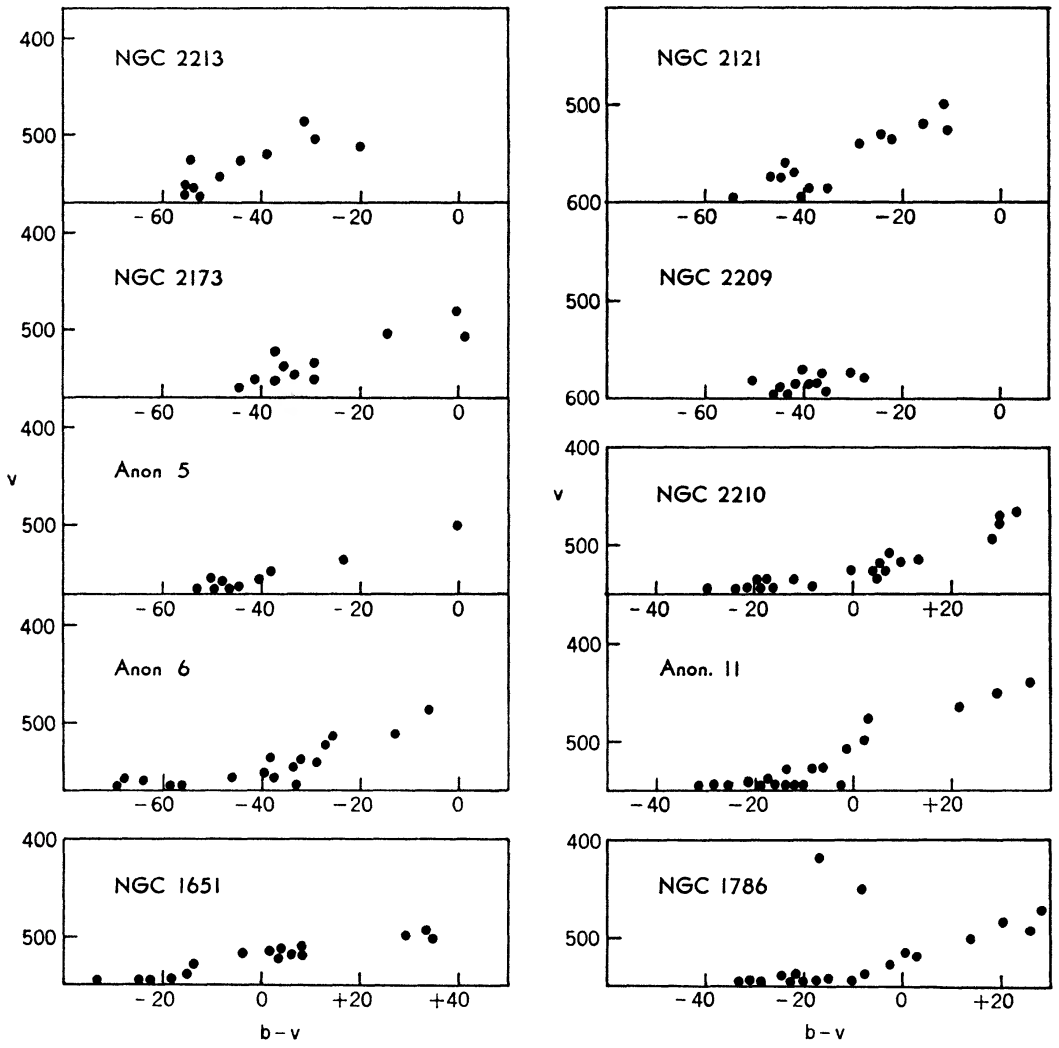

FIG. 5.—Uncalibrated color-magnitude diagrams for 10 more globular clusters

Most of the clusters examined followed the expected rule; either they were definitely globular, or they were not (see Fig. 1). Because a few, however, did not fit into either pattern, examination by other methods seemed advisable. All clusters with globular characteristics, plus the few peculiar clusters, were then examined in more detail. Color-magnitude diagrams were obtained for the brightest cluster members by measurements with an Eichner astrophotometer on one plate in each color. Because of the lack of accurate sequences, the diagrams could not be calibrated; however, the existence of a number of clusters on each plate allowed frequent intercomparisons of diagrams. Whenever there was a peculiar cluster, there was always a nearby normal globular for comparison. The astrophotometer measurements therefore gave much information on the shape of the color-magnitude diagram, although accurate data on the magnitudes were not obtained. Such uncalibrated diagrams have been discussed by Burbidge and Sandage (1958).

III. RESULTS

The Catalogue

A total of 35 clusters of the Large Magellanic Cloud could be definitely assigned to the globular-cluster class as defined by their color-magnitude diagrams. These are listed in Table 1. The diameters listed in Table 1 are estimated from the blue plates and are intended merely as guides for future investigators. The degree of concentration toward the center has been estimated according to classes as defined by Shapley and Sawyer (1927) and is also given in Table 1. Table 2 lists three possible globulars.

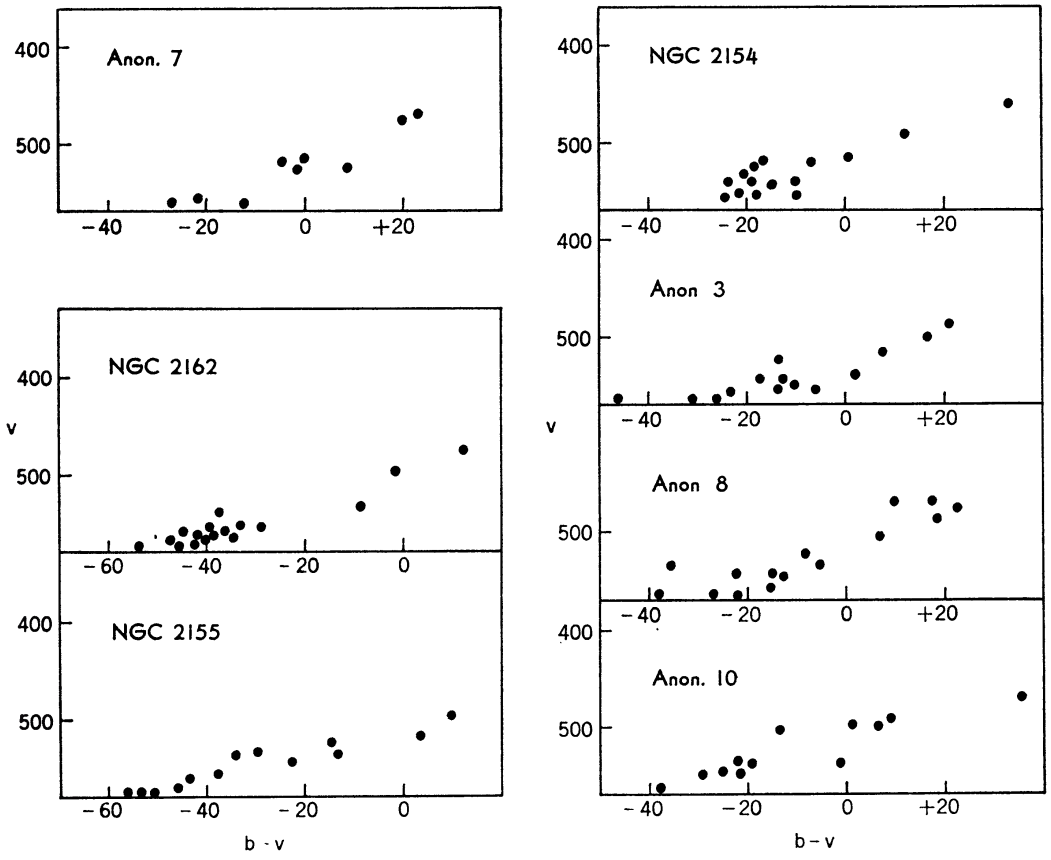

FIG 6.—Uncalibrated color-magnitude diagrams for 7 more globular clusters

The Distribution

The globular clusters are distributed across the face of the Cloud as shown in Figure 2. Few outer clusters appear on the western side of the Cloud; none were found there beyond the main body of the galaxy. In the eastern part, however, the clusters extend well beyond the easily visible parts of the Galaxy, and probably beyond the limits of this

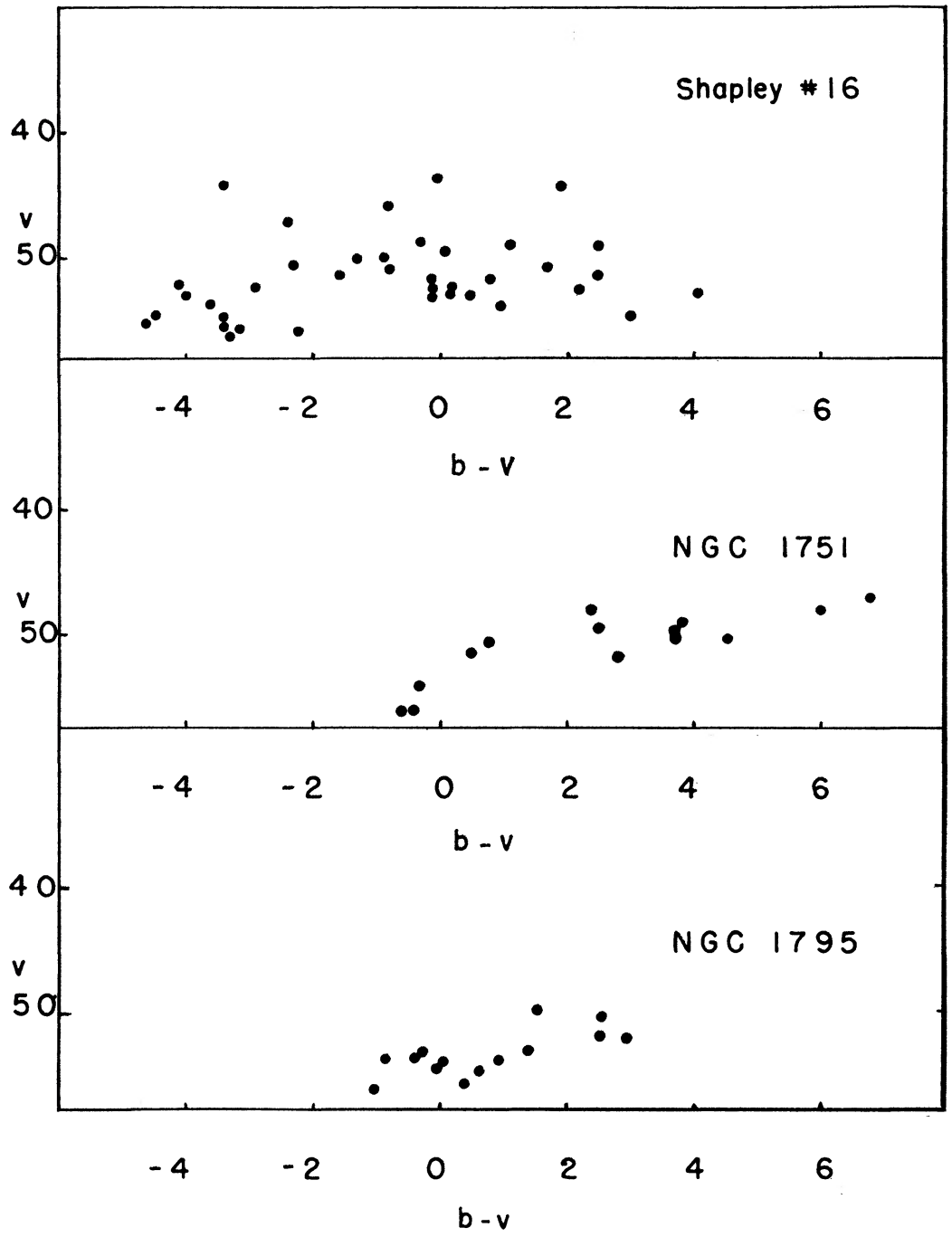

FIG. 7.—Uncalibrated color-magnitude diagrams for two red globular clusters and a "blue globular" measured on the same plates

search. West of 5^h20^m, which passes through the usually accepted center of the Cloud, there are 14 clusters, while east of this line there are 21. Finding charts are provided in Figures 3*a*–3*d*.

The Color-Magnitude Diagrams

Figures 4, 5, 6, and 7 show the uncalibrated color-magnitude diagrams for 27 globulars. The diagrams for 4 others—NGC 1898, NGC 1917, Anon 1, and Anon 2—are not shown because of irregularities in the yellow plate. Calibrated color-magnitude diagrams for NGC 1846, NGC 1978, and Anon 4 will be given in other papers of this series. Measurements of stars in the cluster NGC 1783 have been carried out by Eggen and Sandage, and that cluster is also not shown here. The reproducibility of the uncalibrated color-magnitude diagram is illustrated by the cluster Anon 3, shown in the diagrams twice because it was measured completely independently on two sets of plates. Figure 7 shows the uncalibrated color-magnitude diagrams for the two globular clusters, NGC 1751 and NGC 1795, measured on the same plates. These illustrate a difference occasionally detected between clusters in the redward extension of the giant branches. The uncalibrated color-magnitude diagram for the cluster NGC 2209 (Fig. 5) has an unusually faint giant branch. The cluster NGC 1718 has an even fainter giant branch, which is nowhere brighter than V = about 17.5. Such differences may indicate a relatively higher metals abundance for these clusters (Arp 1958). Their giant branches are still brighter than that of M67 (Johnson and Sandage 1955), which probably has a heavy-element abundance like that of population I.

Figure 7 also shows the uncalibrated color-magnitude diagram for the cluster Shapley No. 16 (Shapley 1931). This cluster is definitely not a globular. It is difficult to identify it with any known cluster in our Galaxy. It possibly represents the cluster type investigated by Arp (1959). He suggests that NGC 458, which has its brightest stars at intermediate colors, contains young stars of low metal content. A similar explanation may apply here. Accurate photometry, utilizing plates of as large scale as possible in conjunction with a photoelectric sequence in the immediate neighborhood of the cluster, is needed to study such objects, which apparently abound in the Large Magellanic Cloud.

I am indebted to Professors Cecilia Payne-Gaposchkin and D. H. Menzel for making it possible for me to work at the Boyden Observatory in South Africa and to Professor H. Haffner, who made my stay there pleasant and profitable. Dr. Allan Sandage suggested that this project be undertaken, and I am indebted to him for very valuable discussions.

REFERENCES

Arp, H. 1958*a*, *Handbuch der Physik* (Berlin: Springer), **51**, 75
———. 1958*b*, *A.J.*, **63**, 118
———. 1959, *ibid*, **64**, 175.
Burbidge, E. M., and Sandage, A 1958, *Ap. J.*, **127**, 527.
Gascoigne, S. 1954, *Australian J. Sci.*, Vol. **17**, Suppl.
Gascoigne, S., and Kron, G 1952, *Pub. A.S P.*, **64**, 196
Johnson, H., and Morgan, W. 1953, *Ap. J.*, **117**, 313
Johnson, H., and Sandage, A. 1955, *Ap J.*, **121**, 616
McCuskey, S. 1935, *Harvard Circ.*, No 401
Sandage, A. 1957, *Mt. W. and Palomar Obs Ann. Rept.*
———. 1958, *Ap. J.*, **127**, 513.
Schmidt, Th 1957, *Zs. f Ap.*, **41**, 182.
Shapley, H. 1931, *Harvard Bull.*, No. 884.
Shapley, H., and Sawyer, H. 1927, *Harvard Bull.*, No 824
Thackeray, A., and Wesselink, A. 1953, *Nature*, **171**, 693
Vaucouleurs, G de. 1955, *A.J*, **60**, 126.