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THE NGC 5128 GLOBULAR CLUSTER SYSTEM

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ABSTRACT

Of 13 visually selected globular cluster candidates observed with the SIT vidicon and Cassegrain spectrograph at the CTIO 4 m telescope in 1981, 12 are clusters with heliocentric radial velocities in the range +340 to +860 km s^{-1}. In 1982 three additional clusters were found by spectroscopic observations of a sample of 13 objects chosen to have $B-V$ colors in the range of the confirmed, visually selected clusters. Combining these results with observations obtained in 1980 brings to 20 the number of spectroscopically confirmed globular clusters associated with NGC 5128. From them we find the following: (1) The clusters have $17.0 < V < 18.7$ and $0.71 < B-V < 1.16$ mag; and, in the mean, the redder, more metal-rich clusters lie at smaller galactocentric distances than do the bluer clusters. (2) The brightest clusters are probably similar in luminosity and size to, or brighter than, ω Cen, the most massive and luminous globular cluster in the Galaxy. (3) In projected distance the confirmed clusters lie between (2.9 and 35.6)(D/5) kpc from the nucleus. That is, they lie primarily outside the main body of the optical galaxy, a tendency likely to have resulted from selection effects. (4) Application of a projected mass estimator to our velocity data suggests that NGC 5128 has a mass of $\approx 1.6 \times 10^{12}$ $(D/5)$ $M_\odot$ within $\approx 36(D/5)$ kpc. The implied value of the mass-to-light ratio, M/L_V, is $\approx 16(5/D)$ in solar units. Analysis of velocities of companion galaxies within 350(D/5) kpc suggests that there is mass in the NGC 5128 halo (or in the NGC 5128 cluster of galaxies) at or beyond the radius of the most distant star clusters that have so far been identified around NGC 5128, itself. (5) New Star counts support the existence of a substantial cluster system of ≈ 600 members, as does spectroscopic discovery of three new clusters in a complete sample of *photometrically* selected candidates. (6) Comparison of the observed NGC 5128 globular cluster luminosity function with that of the clusters of the Local Group galaxies, scaled to a total population of ≈ 600, suggests either that the brightest NGC 5128 clusters are ≈ 1 mag more luminous than the most luminous globulars in the Galaxy or that the distance to NGC 5128 is ≈ 3 Mpc. We believe that the latter interpretation is more probable. (7) The distribution on the sky of the visually selected candidates and of the spectroscopically confirmed clusters hints at a *possible* preferential orientation of the cluster system with its major axis aligned along the major axis of the isophotes of the outer spheroid of the galaxy. Other topics discussed include selection effects, properties of the radial velocities, and the luminosity of SN 1972e in NGC 5253.

Subject headings: clusters: globular — galaxies: individual — galaxies: stellar content

I. INTRODUCTION

For many years the lack of a globular star cluster system was accepted as yet another peculiarity of the nearest giant elliptical galaxy, NGC 5128 = Cen A. This galaxy, a classical, strong, double-lobed radio source, is also noted for a host of unusual, often striking, characteristics. Among these are: (1) a thick dust band and associated evidence for vigorous star formation; (2) a "jet" that appears at radio, optical, and X-ray wavelengths, and which provides evidence for very recent star formation to at least 20(D/5) kpc from its nucleus; and (3) detectability at γ-ray energies. Radial velocity observations by Graham (1979) led him to revive Baade and Minkowski's (1954) suggestion that NGC 5128 represents two galaxies in collision, an idea which had originally been proposed in order to explain the presence of dust in an elliptical galaxy. From a recent Fabry-Perot interferometric study of its velocity field Marcelin *et al.* (1982) have proposed the radically different idea that NGC 5128 is an S0 or Sa spiral galaxy whose disk formed very late relative to the spheroid.

Undoubtedly its low galactic latitude ($b = +19°$) and the accompanying problems of foreground star and background galaxy contamination prevented the discovery of NGC 5128's globular cluster system for many years (cf. Sérsic 1960; Evans and Harding 1961; de Vaucouleurs 1979; van den Bergh 1979) until Graham and Phillips (1980, hereafter GP) demonstrated the existence of a bright globular cluster near the NE optical jet (Blanco *et al.* 1975; Peterson, Dickens, and Cannon 1975) 8′.2 (1′ ≈ 1.5 kpc if D = 5 Mpc) from the nucleus. On good seeing plates their cluster is slightly nonstellar in appearance.

Soon thereafter six additional cluster candidates were

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identified and four were spectroscopically confirmed as globular clusters by van den Bergh, Hesser, and Harris (1981, hereafter Paper I), who also used star counts to estimate a total cluster population above their plate limit of ≈ 600. These results, as well as those of GP, de Vaucouleurs (1980), and Frogel (1980) for the GP cluster, suggested that either NGC 5128 is closer than the 5 Mpc usually adopted for it (Burbidge and Burbidge 1959) *or* that its brightest clusters are about a magnitude more luminous than ω Cen (NGC 5139 = C1323−470), the most luminous Galactic[4] globular cluster.

In this paper we extend the efforts of Paper I in several directions, some of which have been briefly described elsewhere (Hesser *et al.* 1981, 1982). Spectroscopic observations of two samples of cluster candidates have been obtained with the CTIO 4 m telescope and SIT spectrograph: (1) 13 candidates believed from visual inspection to be nonstellar; and (2) 13 objects selected only by magnitude and color. All told, 20 clusters have now been spectroscopically confirmed. PDS photometry and intensity moment analyses of their images provide information on the color, luminosity, and structural properties of the cluster system, and of selection effects inherent in our data base. The velocity data are used to estimate the mass of NGC 5128, while new star counts made on a UK Schmidt plate centered on NGC 5128 yield information on the total number of clusters. A new distance estimate is made using the cumulative luminosity function of the cluster system.

II. SELECTION OF CANDIDATES

Two different classes of criteria were employed to select objects for spectroscopic observation in 1981 and 1982, respectively. In 1981, the visual appearance (i.e., a slight "diffuseness") was augmented by subsequent PDS image structure analysis. In 1982 a new PDS study was carried out to isolate a complete sample of images having $B-V$ values in the range defined by the sample of previously confirmed clusters.

a) *Criteria Based on Image Structure*

The five confirmed clusters from GP and Paper I were used as guides while visually searching CTIO 4 m telescope prime-focus plates taken in 1975 and 1976 in each of the *U*, *B*, and *V* bands. These exposures were made on 103*a*-D and 103*a*-O emulsions exposed in 1″0 to 1″5 seeing. Images believed to be slightly diffuse in comparison with other nearby images of comparable density were identified. Unfortunately, on these early plates image quality deteriorates at radii in excess of $\approx 15'$, thereby somewhat compromising in a radius-dependent fashion our ability to detect barely nonstellar objects. This initial list of suspected nonstellar images was then examined independently by three of us on the best seeing plate in order to judge each object's likelihood of being a cluster rather than a star or background galaxy. During this procedure several additional candidates were selected by each observer. Candidates to be observed spectroscopically were selected from those ranked as "very probable" or "probable" by at least one of the three visual observers, as well as by the PDS analyses described below.

Each uncrowded candidate was then scanned with the DAO PDS microdensitometer on *B* and *V* plates using a 20 μm square aperture and a grid size of 600×600 μm. Magnitudes, colors, and structural parameters of each image were derived from these PDS scans (cf. § III*b*) in an attempt to separate probable clusters from stars and background galaxies. For example, Figure 1 shows the central surface brightness as a function of visual magnitude. The clusters tend to exhibit a slightly lower central surface brightness than do the stars of similar magnitudes, thereby giving a quantitative measure of the nonstellar character of each visually selected image. Plots of other parameters (cf. § IV*c* and Fig. 8) were also used to assess the nature of each object. Such figures show that there are other cluster candidates that should be studied spectroscopically, and seven of the most promising ones are identified below.

b) *Criteria Based on Photometric Properties*

A large area on each of three plates (P1014, P1016, and P5236) was raster scanned with the KPNO PDS using a 20 μm square aperture. Data for all the images contained in an area $2'.5 \times 6'.2$ located $5'.3$ [or $9(D/5)$ kpc] northeast of the nucleus and thus away from the dust lane were reduced to *V* and *B* values at the DAO by procedures similar to those described in § III*b*. Spectroscopic observations were secured

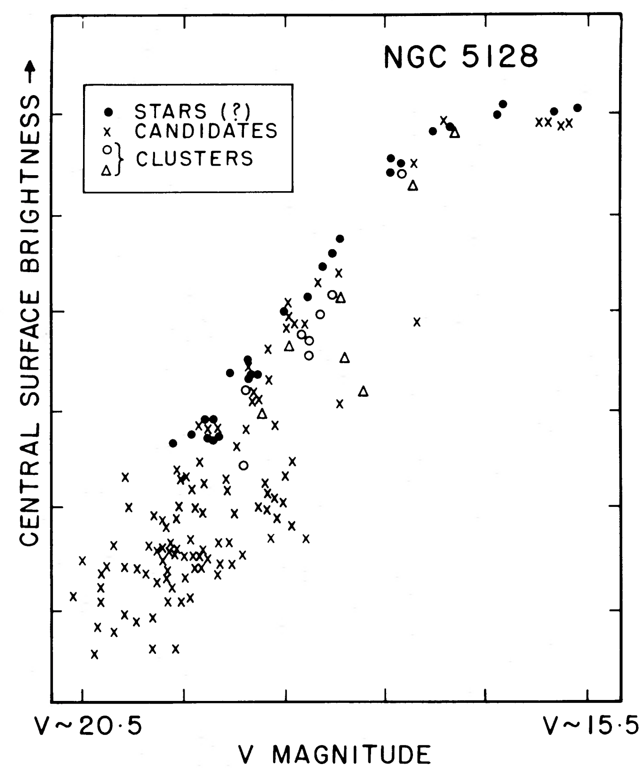

FIG. 1.—The central surface brightness in magnitude units vs. *V* magnitude as measured on plate P1015 for a sample of presumed stars and visually selected globular cluster candidates near NGC 5128. The original seven globular clusters of Paper I are identified by triangles, while eight of the 1981 spectroscopically confirmed clusters are denoted by circles; other candidates are denoted by X's. Presumably most of the X's lying to the extreme right are galaxies, but a few may be clusters similar to GP's (the cluster of lowest central surface brightness for its magnitude).

[4] In order to avoid confusion in this paper, we have adopted the convention of capital G for the Milky Way (i.e., Galactic globulars, Galactocentric) and lowercase g for NGC 5128 (galactic globulars, galactocentric).

for all 13 uncrowded objects having $16.9 < V < 18.6$ and $0.67 < B-V < 1.20$ mag, where the bright magnitude limit and the color range slightly exceed the values for previously confirmed clusters. Although image structure information was a byproduct of the PDS intensity analysis, selection of candidates for spectroscopic observation relied *solely* upon the aforementioned V and $B-V$ criteria. Of the 13 objects observed spectroscopically, three were found to be clusters, only one of which was noted as being nearly as diffuse as cluster 17 (which lies within the area scanned).

Enlargements in Figure 2 (Plate 4) of five fields containing confirmed clusters illustrate the range of spatial properties characterizing the NGC 5128 clusters, and the difficulties encountered in detecting them by visual inspection. In Figure 3 (Plate 5) we present a finding chart for the confirmed clusters and for seven additional suspects with extended images (cf. § III*b*) that we feel are likely to be proven clusters by future spectroscopic observations. The original seven clusters were numbered in order of increasing right ascension, and the new clusters and candidates, beginning with number 8, follow the same convention.

III. SPECTROSCOPIC AND PHOTOMETRIC OBSERVATIONS

a) *Spectroscopic Observations*

Spectra at ≈ 60 Å mm^{-1} and 3–4 Å resolution have been obtained on three runs (1980 June [Paper I]), 1981 April, and 1982 May) with the CTIO 4 m telescope and its SIT vidicon spectrograph. The bulk of this paper is based upon data obtained during the second run, since the first has been described earlier and the third was largely cloudy and used primarily to initiate examination of possible selection effects (see § IV). The instrumental configuration was the same for all three runs, namely 300 μm (2.″0) slit; KPNO Grating Lab grating number 1 (632 lines mm^{-1}) in the first order blue (angle 59°20′); and a 16 mm diameter, UV-transmitting, RCA-4804 SIT vidicon (Atwood *et al.* 1979) with a 250 mm focal length, f/1.4 camera without beam reducing optics.

i) *1981 Observations*

The 1981 observations were obtained on April 3, 4, and 5 UT and benefited from good seeing, though cirrus was present for much of the night of April 5. Following the precepts outlined elsewhere for obtaining velocities of ≈ 25 km s^{-1} precision with the SIT (Hesser and Harris 1981), we bracketed each NGC 5128 observation by an exposure with the He-Ar comparison lamp. We also observed stars in four Galactic globular clusters (cf. the Appendix) during the seven nights that the present instrumental configuration was in use for this and another program. In particular, stars ROA 40 and ROA 65 in nearby ω Cen were monitored frequently (after the first night) for possible time- and/or position-dependent shifts in the velocity system. None were found.

Reductions of the 1981 data to wavelength and (approximate) flux scales were made with the "old" version of the La Serena software system (Schaller *et al.* 1978) operative in 1981 April. This system was augmented by several very helpful routines (including a cross correlation one for reducing the He-Ar spectra) implemented for us by Jack Baldwin. The overall behavior of the velocity system was similar to that found earlier (cf. Hesser and Harris 1981) but, contrary to their experience, no zero-point correction was required to bring the reduced velocities of Galactic objects on to the system defined by other investigators (see the Appendix).

In all but two cases the 1981 spectroscopic observations were of "diffuse" images selected as described in § II*a*. (The exceptions were two objects selected by visual examination of the 1981 plates taken just prior to the SIT run [cf. § III*b*].) Thirteen candidates were observed in 1981; in addition, three clusters from the 1980 run were reobserved. Our goal was to sample as many candidates as possible in order to evaluate the efficacy of our visual selection criteria and to survey the spatial extent and velocity dispersion of the NGC 5128 cluster system. Because of the extreme faintness of these objects, the spectra tend to be rather noisy, although adequate for our purposes. The spectra shown in Paper I are typical of the 1981 data as well. In spite of good observing conditions, we were unable to complete our list of faint, highest priority, visually selected suspects.

ii) *1982 Observations*

The NGC 5128 data obtained during a (predominantly) cloudy observing run in 1982 stem almost entirely from the night of May 20/21. Thirteen "stellar" candidates, selected as described in § II*b*, were observed beginning at the bright end of the list following the same procedures as used previously. Reduction to wavelength and approximate flux scales used the "new" version of the La Serena software system (Schaller 1982). Although the weather prevented our observing a large sample of stars with known velocities, we believe (cf. the Appendix) the 1982 data are essentially on the same velocity system as their 1981 counterparts. As a consequence of very poor transparency conditions, the observations of cluster 24 (which is also crowded—see Fig. 2) exhibit a very low signal-to-noise (S/N) ratio. We cannot therefore judge if its spectrum is composite in nature, but its high velocity argues for association with NGC 5128. (Even poorer S/N ratio data for cluster 17, obtained immediately after those for cluster 24, were capable of revealing its high velocity). Although we believe that object 24 is a bona fide, high-velocity object, we caution that our measurement of its velocity is very uncertain.

iii) *Summary of the Spectroscopic Observations*

The velocities derived are summarized in Table 1, where the objects are listed in order of decreasing B magnitude which approximates more closely than V the cluster brightness in the region (3800–4500 Å) studied. The column headings are largely self explanatory (σ_m is the formal standard deviation of the mean). In cases where the exposure time is greater than 45 minutes, the total exposure time in Table 1 represents the summation of individual exposures.

Of the 13 new candidates observed spectroscopically in 1981, 12 proved to have heliocentric velocities in the range +340 to +860 km s^{-1}. On that basis alone they are likely to be associated with NGC 5128, whose systemic velocity is ≈ 550 km s^{-1} (cf. Graham 1979 and § V*a*, below).[5] Additionally, most candidates appear to have spectra exhibiting the characteristics of a composite stellar system. Possible

[5] The only visually selected candidate not falling within the velocity range appropriate for NGC 5128 was one of the two picked out at the telescope. This candidate, which lies $\approx 0.°5$ from the nucleus of NGC 5128, turned out to be a galaxy with $V \approx 16{,}500$ km s^{-1} and is not included in Fig. 3.

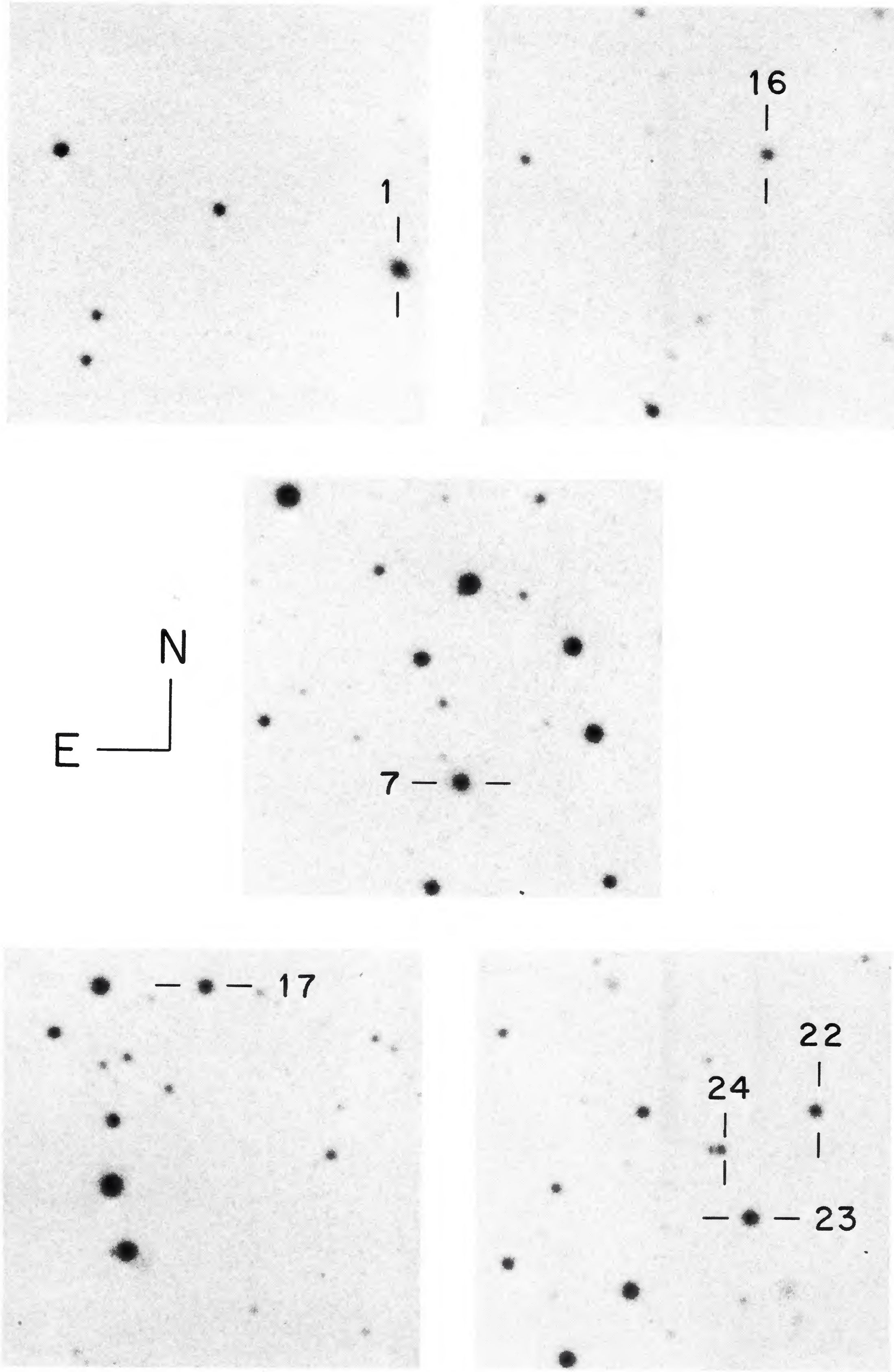

FIG. 2.—Enlargements of regions near seven of the confirmed clusters (see Table 3) made from CTIO plate P5236. Cluster 7 is GP's cluster; clusters 22–24 were selected photometrically, and all others were selected from the slightly nonstellar appearance of their images. Each field is ≈ 1.2 high.

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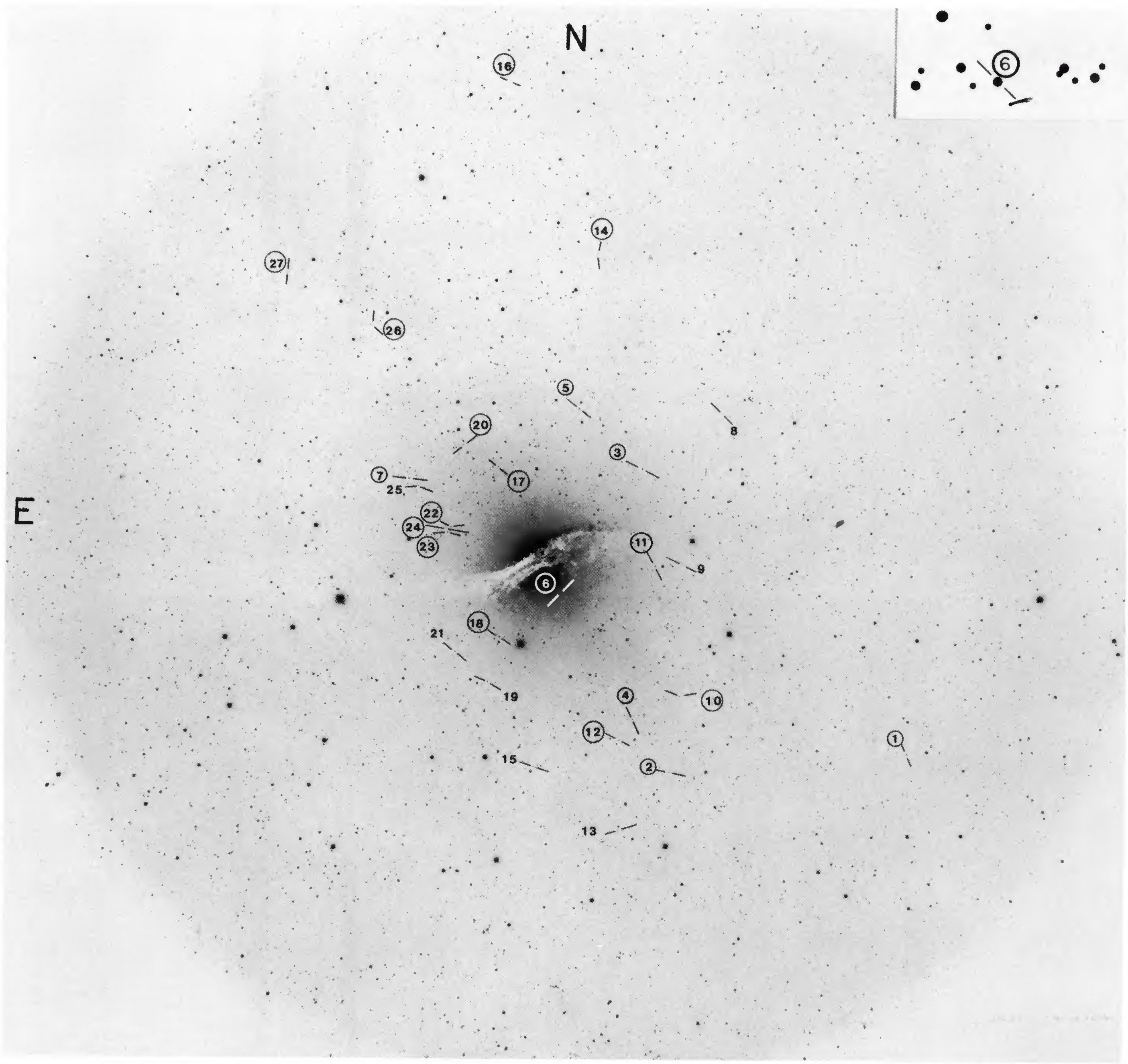

FIG. 3.—A finding chart in yellow light from CTIO 4 m telescope plate P1015 (see Table 2). Spectroscopically confirmed clusters have encircled identification numbers, while other visually selected candidates of high promise do not. The field of view is ≈ 50′ in diameter. The insert sketch of the field of cluster 6 is ≈ 1′ high in the N–S direction.

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TABLE 1

1981–1982 Spectroscopic Observations of NGC 5128 Clusters

Object ID: Fig. 3	Object ID: Internal	Date (UT)	Exp. (min.)	$V_{r,\odot}$ (km s^{-1})	σ_m (km s^{-1})	No. Lines	Notes[a]
7	7	1981 Apr 3	20	683	18	8	1
6	6	1981 Apr 4	25	782	54	9	
5	5	1981 Apr 5	60	521	14	7	2
23	82–107	1982 May 21	60	688	19	11	3
18	207	1981 Apr 3	45	523	21	9	
17	8	1981 Apr 3	60	859	26	10	
14	501	1981 Apr 5	63	710	49	7	
4	4	1981 Apr 4	60	638	51	5	4
20	123	1981 Apr 3	55	801	41	8	
11	o	1981 Apr 4	60	796	31	7	
12	15	1981 Apr 4	60	445	24	12	
22	82–95	1982 May 21	30	641	32	8	
26	gg	1981 Apr 4	30	315	43	9	
		1981 Apr 5	90	345	18	7	
27	a	1981 Apr 4	90	495	45	6	5
2	2	1981 Apr 3	90	644	55	8	
10	21	1981 Apr 5	90	771	46	10	
24	82–105	1982 May 22	38	309::	25	9	6
16	78	1981 Apr 4	90	492	50	8	

[a] Notes.—(1) GP's analysis of their image-tube spectrum gave $V_{r,\odot} = 568$ km s^{-1}. Our Paper I 60 minute SIT spectrum gave $V_{r,\odot} = 571$ km s^{-1}. We have adopted 599 km s^{-1} for subsequent analysis. (2) The 60 minute SIT spectrum of Paper I gave $V_{r,\odot} = 502$ km s^{-1}. For subsequent analysis 512 km s^{-1} has been adopted. (3) $V_{r,\odot}$ is the average of two, nonconsecutive 30 minute observations on the same night, one ending at hour angle 3:44 W ($V_{r,\odot} = 675$ km s^{-1}) and the other at 4:59 W (702 km s^{-1}). (4) A 45 minute SIT spectrum at high hour angle and with only four measurable lines gave $V_{r,\odot} = 691$ km s^{-1} (Paper I). We adopted 661 km s^{-1} for the subsequent analysis. (5) As a consequence of crowding along the E-W oriented slit, the sky subtraction is less reliable. (6) A very weak exposure due to clouds. We only consider the $V_{r,\odot}$ to be indicative of association with NGC 5128, and we do not use the velocity for subsequent analyses.

exceptions are objects 12, 27 (for which the sky subtraction is less secure—see Table 1), and 10, which are among the faintest we observed. Thus, of 18 visually selected candidates observed spectroscopically in 1980–1981, 17 appear to be globular clusters—a (fortuitous?) success rate of $\approx 94\%$.

Of the three clusters from Paper I that were reobserved in 1981, one (cluster 4) was reobserved because its 1980 data were obtained at large hour angle. No significant difference was detected between the 1980 and 1981 data. Clusters 5 and 7 were also reobserved. In the case of cluster 5 agreement is excellent, and in the case of cluster 7 it is poor. The latter disagreement is not as distressing as it might appear because it was the first observation of the first night of the 1981 run and was only 20 minutes long (compared to 60 minutes in 1980). It was obtained only to provide a rough calibration of the zero-point of the "quick look" system before undertaking the survey. We thus remain reasonably confident in the overall velocity system and have combined the velocities from the 1980 and 1981 seasons by weighting them according to exposure time.

For the 1982 observations of apparently "stellar" images in the vicinity of NGC 5128, three of the 13 color-selected candidates have velocities indicative of association with NGC 5128, and two of these are also the only 1982 spectra which appear to be composite in nature. Interestingly, cluster 23 discovered during the 1982 survey is the third brightest cluster (in V) yet discovered in NGC 5128. These results support the existence of a significant population of clusters predicted by the star counts (Paper I and § VI), most of which cannot be distinguished from stars by visual selection with presently available plate material. The radial velocities of the remainder of the 1982 candidates ranged from -110 to $+200$ km s^{-1} [$\langle V_{r,\odot} \rangle = 16 \pm 32$ (m.e.) km s^{-1}]. On the basis of radial velocity and spectral classification criteria we judge them to be field stars and exclude them from Figure 3.

b) Photometric Observations

The available 4 m prime-focus plates described in Table 2 include first plates from a new survey of the outer regions of NGC 5128. Unfortunately we were able to complete only the NE region in both B and V with the Pickering (1891)–Racine (1969) prism (indicated as P-R in the column headed "Plate" in Table 2), which was used whenever it was available.[6] Visual inspection of the plates listed in Table 2 is continuing, and a number of promising new candidates have been identified.

The visually selected cluster candidates, as well as presumed stars and galaxies, were scanned (as described in § II) with the DAO PDS microdensitometer in late 1981 April. Three plates (P5236, P5237, and P5254) were calibrated using the secondary images of Graham's (1981) photoelectric sequence stars. Since

[6] We chose IIa-O and IIa-D rather than IIIa-J and IIIa-F plates for this experiment after inspection of our clusters and candidates on one of John Graham's excellent seeing IIIa-J plates suggested that visual identification of barely nonstellar objects would be easier on the IIa emulsions. The reason for this may be that the higher contrast of the IIIa emulsions masks subtle intensity gradients.

TABLE 2

JOURNAL OF AVAILABLE 4 METER TELESCOPE PRIME FOCUS PLATES

Plate	Date	Observer[a]	Exp. (min.)	Emulsion	Filter	Comments
P1013	1975 Apr 12	vdB	12	103a-O	GG 385	
P1014	1975 Apr 12	vdB	12	103a-O	GG 385	
P1015	1975 Apr 12	vdB	15	103a-D	GG 495	
P1016	1975 Apr 12	vdB	15	103a-D	GG 495	
P1031	1975 Apr 14	vdB	45	IIIa-J	GG 385	
P2109	1976 Jun 20	RJD	25	103a-O	UG 2	
P2110	1976 Jun 21	RJD	45	103a-O	UG 2	
P5236 + P-R	1981 Apr 1	JEH	15	IIa-D	GG 495	
P5237 + P-R	1981 Apr 1	JEH	15	IIa-D	GG 495	20′N 20′E
P5238 + P-R	1981 Apr 1	JEH	15	IIa-D	GG 495	20′N 20′W
P5251 + P-R	1981 Apr 2	JEH	15	IIa-D	GG 495	20′S 20′E
P5253 + P-R	1981 Apr 2	JEH	10	IIa-O	GG 385	20′S 20′W
P5254 + P-R	1981 Apr 2	JEH	10	IIa-O	GG 385	20′N 20′E
P5255	1981 Apr 2	JEH	10	IIa-O	GG 385	20′N 20′W
P5256	1981 Apr 2	JEH	10	IIa-O	GG 385	20′S 20′E

[a] vdB: van den Bergh; RJD: Dufour; JEH: Hesser.

we obtained magnitudes by integrating the intensity images, we eliminated (to first order, at least) the effects of differing structure, if any, between the primary and secondary images that may affect iris photometry (Racine 1969; Blanco 1982). A Δm of 7.00 mag between primary and secondary images was adopted for the NGC 5128 plates. Subsequent analysis of Cannon and Stewart's (1981) larger sample of photoelectrically measured stars on ω Cen plates (which were taken expressly to calibrate the prism on each of the same two nights used for prime focus observing of NGC 5128), suggests that perhaps $\Delta m = 6.95$ mag is marginally more appropriate. In this case the magnitudes adopted herein would need to be made brighter by 0.05 mag. For plates lacking P-R images, we used secondary standards calibrated on plates containing both the photoelectric sequence stars and P-R images. Visual magnitudes were determined from plates P1015, P5236, and P5237, and blue magnitudes were determined from P1013, P1014, and P5254. The photometry for the multiply observed candidates has a mean internal error for one observation of 0.06 mag. We have not made an exhaustive study of possible systematic errors in the photometry, but we expect that they are <0.1 mag.

The results of these efforts are given in Table 3, where the column headings are largely self-explanatory. (If in the seventh column the number of plate pairs used is 2, then magnitudes from plates P5237 and P5254 were not available for inclusion in the means. Note also that the velocities are rounded to the nearest 10 km s^{-1}). The last seven objects in the table are *candidates* we believe to have a high probability of being clusters, but for which no radial velocities are yet available.

IV. PROPERTIES OF THE CLUSTERS

With our sample of 20 confirmed and seven suspected globular clusters we can now attempt to infer some global properties of the NGC 5128 globular cluster system. The conclusions below are somewhat tentative, however, for two reasons. First, small-number statistical fluctuations are important in a sample of only 27 objects. Second, the selection processes are biased against certain kinds of clusters. These selection effects are probably quite important in some areas and complicate interpretation of our results. Consequently, it is necessary to keep in mind how each sample of clusters was chosen. In the following paragraphs we therefore sometimes separate the subsample of 17 clusters identified on the basis of their extended images (sample A) from the subsample of three clusters selected from photometry in the small region near the center of NGC 5128 (sample B). We refer to the 20 confirmed and seven probable clusters as the "combined sample." Furthermore, the discussions of this section will occasionally require a value of the distance to NGC 5128. Anticipating the analyses of § VI, we frequently adopt a value of 3 Mpc rather than the 5 Mpc usually quoted, although we also parameterize our results in terms of $D/5$ Mpc to facilitate comparison with the NGC 5128 literature.

a) Colors and Magnitudes of the Clusters

A wide range of colors is observed for the clusters (see Fig. 4), a range that extends beyond the red limit observed for

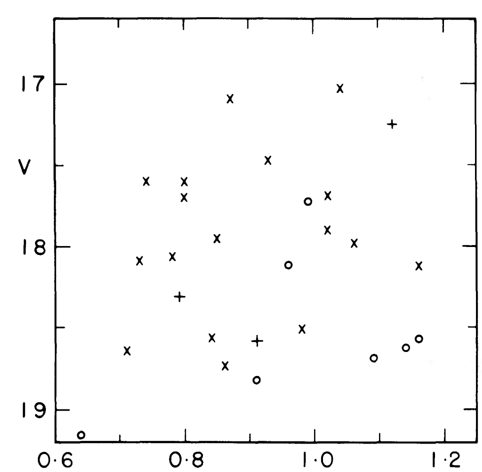

FIG. 4.—A color-magnitude diagram for the combined NGC 5128 cluster sample. The symbols used are: X's indicate sample A clusters; +'s are the sample B clusters; and the open circles represent visually selected cluster candidates.

TABLE 3

VALUES ADOPTED FOR POSITION, PHOTOMETRY, AND VELOCITY

OBJECT	DISTANCE arcmin	DISTANCE kpc(D/5)	$\langle V \rangle$ (mag.)	$\langle B \rangle$ (mag.)	$\langle B \rangle - \langle V \rangle$ (mag.)	N	$\langle V_{r,\odot} \rangle$ (km s^{-1})
7	8.1	11.8	17.09	17.97	0.88	3	600
6	2.0	2.9	17.03	18.07	1.04	2	780
5	8.2	11.9	17.60	18.34	0.74	3	510
23	4.9	7.1	17.25	18.37	1.12	2	690
1	21.5	31.3	17.60	18.40	0.80	2	690
18	4.7	6.8	17.47	18.40	0.93	2	520
17	5.3	7.7	17.70	18.50	0.80	3	860
3	7.2	10.5	17.70	18.72	1.02	2	590
14	15.9	23.1	17.96	18.81	0.85	3	710
4	9.5	13.8	18.09	18.82	0.73	2	660
20	7.2	10.5	18.06	18.84	0.78	3	800
11	5.8	8.4	17.90	19.02	1.12	2	800
12	10.1	14.7	17.98	19.04	1.06	2	440
22	4.8	7.0	18.31	19.10	0.79	2	640
26	14.9	21.7	18.12	19.28	1.16	3	340
27	19.6	28.5	18.65	19.36	0.71	3	500
2	12.8	18.6	18.56	19.40	0.84	2	640
10	10.0	14.5	18.50	19.48	0.98	2	770
24	4.9	7.1	18.59	19.50	0.91	2	...
16	24.5	35.6	18.73	19.59	0.86	3	490
21	6.5	9.5	17.72	18.81	1.09	1	...
19	6.9	10.0	18.11	19.07	0.96	1	...
25	7.3	10.5	18.56	19.72	1.16	1	...
13	14.4	20.9	18.81	19.72	0.91	1	...
15	10.6	15.4	18.62	19.76	1.14	1	...
8	11.9	17.2	18.68	19.77	1.09	1	...
9	7.2	10.5	19.16	19.80	0.64	1	...

Galactic globulars [$(B-V)_0 \approx 0.9$ mag]. With $E(B-V) = 0.10$ mag for NGC 5128 (van den Bergh 1976), clusters 11 and 26 and several candidates have $(B-V)_0 > 0.9$ mag. If no errors have crept into the photographic photometry for these objects, they must either be reddened by local absorption or be intrinsically very red. Cluster 11 may lie behind part of a dust lane, but cluster 26 certainly does not.

Figure 5 reveals a tendency for the bluest (and presumably most metal-poor) clusters to lie at greater radial distances from NGC 5128. Only one confirmed cluster (cluster 11) and two likely candidates (clusters 9 and 21) are seen projected on the dust lane, and if they are omitted, the tendency remains. The mean $B-V$ color for all 27 probable clusters is 0.93 mag. The mean projected distance for the 14 clusters with $B-V < 0.93$ is $17.0 \pm 2.5(D/5)$ kpc, while that for the 13 clusters with $B-V > 0.93$ is $11.5 \pm 1.5(D/5)$ kpc. The correlation of color with position is only marginally significant (at the 70% confidence level), but the sense and slope of the correlation (-0.007 mag kpc^{-1} for a distance of 3 Mpc) agrees with the slope of the color versus distance relation found in our Galaxy (-0.008 mag kpc^{-1}; Harris and Racine 1979). Accounting for projection effects in the present NGC 5128 sample will change the observed gradient, but it still will agree with that found in our Galaxy to well within the errors. Finally, we note that no color bias was, to our knowledge, introduced in the visual selection procedure or in the subsequent spectroscopic observations of sample A clusters. Nevertheless the absence of populous blue clusters of the Magellanic Cloud type in our sample is not surprising, as our candidates tend to lie away from the dust band where such objects presumably would be found. It might be interesting to ascertain spectroscopically if any of the dozen objects mentioned by van den Bergh (1979) to lie near the dust band are populous blue clusters.

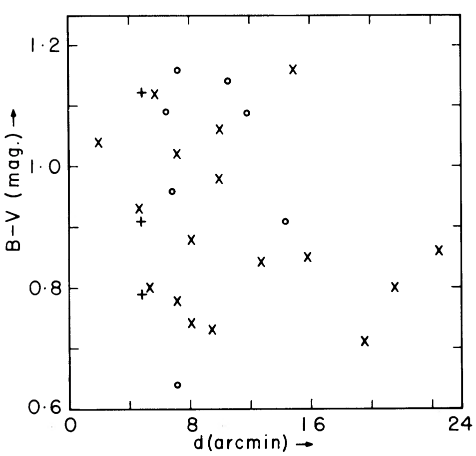

FIG. 5.—$(B-V)_{pg}$ vs. projected distance (arcmin) for the combined sample. The symbols are as in Fig. 4. This figure suggests that clusters lying at smaller projected distances are on average redder and, hence, presumably more metal-rich than those at large distances.

Inspection of Table 3 reveals a tendency *in our sample* for the fainter clusters to lie at greater radial distances from the galaxy. This effect is illustrated in Figure 6, which shows the visual

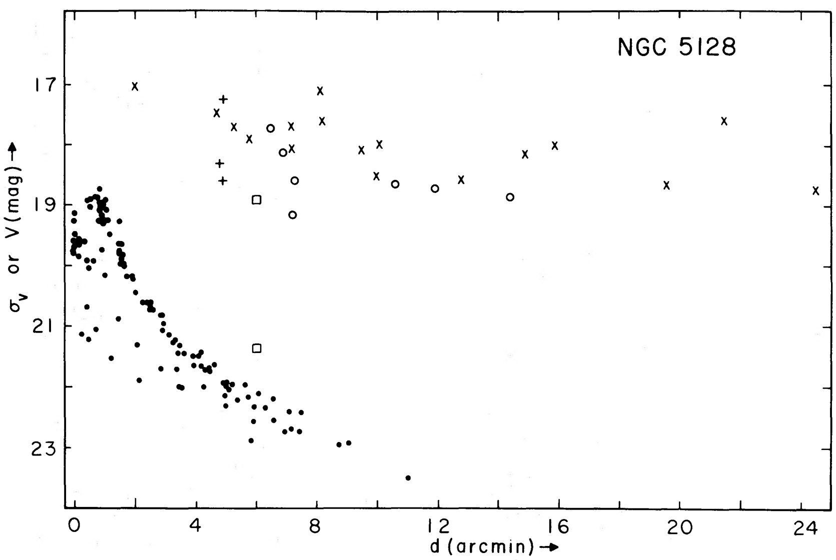

FIG. 6.—The V magnitude for clusters and the surface brightness, σ_V, for the underlying NGC 5128 light (van den Bergh 1976) are plotted as a function of projected radial distance (in arcmin) from the center of the galaxy. The symbols used as as follows: X's indicate sample A clusters; +'s are the sample B clusters; open circles represent visually selected cluster candidates; and the dots give van den Bergh's (1976) surface brightness measures for NGC 5128, itself, from his Table 1. Finally, two squares, arbitrarily placed at 6′, represent the typical central surface brightness of the cluster images on our plates and a value arbitrarily reduced by a factor of 10 to represent the outer parts of the images. A tendency for more distant sample A clusters and suspects to be fainter is apparent.

magnitudes for the combined sample plotted against projected distance in arc minutes from NGC 5128. The 13 brightest clusters have a mean projected distance of $12.3 \pm 2.1(D/5)$ kpc compared to $16.9 \pm 2.3(D/5)$ kpc for the 13 faintest. Errors in the photographic photometry are much too small to account for the difference. A bias against visually selecting faint extended clusters against the background light of the galaxy could account for a deficiency of faint clusters with distances less than $\approx 3'$ to $4'$ or $5(D/5)$ kpc. However, we believe that beyond a radius of $3'$–$4'$ the background light is no longer a serious problem for two reasons: (1) our plates are not very deeply exposed, having background specular densities of, typically, only 0.7 above clear plate at that radius; and (2) the cluster images have a central surface brightness, typically, a factor of 10 above the 21.4 mag arcsec^{-2} background surface brightness of NGC 5128 at that radius (cf. Fig. 6). Another bias which may be important to explain why we find fainter clusters at larger distances arises from the difficulty of identifying faint, compact clusters. Because we find that extended clusters are rare in the inner regions of the galaxy (see § IV*b*), we are left with primarily bright (and compact) clusters in our sample nearer the center of NGC 5128.

b) *Sizes of the Clusters*

Since the clusters in sample A are resolved on our best plates, we are able to estimate their sizes. This was done by converting the photographic density into intensity and then measuring the point spread function (PSF) for a number of stars on the plate with the highest resolution (P5236). The FWHM on this plate is 1″.0.[7] We then constructed models of clusters using King (1962) profiles with various core and tidal radii and an assumed distance, convolved them with the PSF, and fitted them to the observed cluster profiles. Since an acceptable fit could be obtained for several combinations of core and tidal radius, we were unable to determine each individually. Almost any ratio of tidal/core radius reasonable by Galactic standards usually produced an adequate fit within the uncertainty in the observed profile. Therefore, we assumed a ratio of $r_t/r_c = 33$, typical for Galactic globulars.[8]

The sizes derived relative to the above reference model are plotted in Figure 7 for 16 of the sample A clusters. Cluster 6

[7] Although the measured PSF is slightly broader near the edges of the plate, this difference is insufficient to affect our conclusions.

[8] Strictly speaking, a King model is not appropriate for a nonspherical cluster, and cluster 1 is noticeably elongated (see Fig. 2). However, our procedure is still adequate to determine approximate sizes. We note here that, in the Galaxy, ω Centauri is both the most luminous ($M_V = -10.2$) and the most flattened globular. Perhaps the noticeable flattening of cluster 1 also points to high intrinsic luminosity. (With $V = 17.6$, $A_V = 0.3$ [van den Bergh 1976] and $D = 5$ Mpc cluster 1 would have $M_V = -11.2$.)

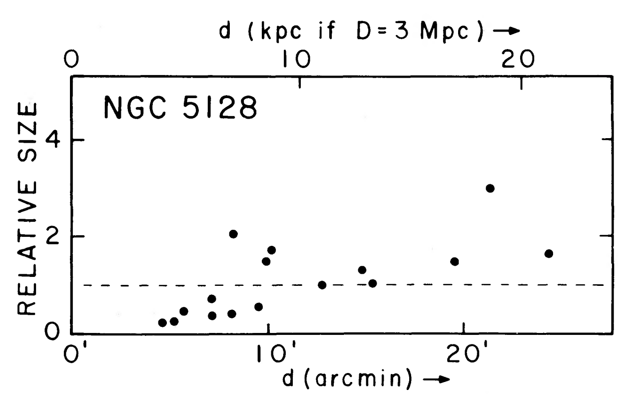

FIG. 7.—The size of 16 sample A clusters vs. projected distance relative to a King model with $r_c = 5(D/5)$ pc and $r_t = 170(D/5)$ pc. The dashed line represents the adopted reference model.

was not included because the high background from NGC 5128 makes its size very uncertain. The three confirmed clusters from sample B are also excluded since their images are not resolved sufficiently for us to obtain a meaningful size. Most of the clusters plotted in Figure 7 range from about as large as ω Cen (one of the largest in the Galaxy, with $r_c = 4$ pc and $r_t = 90$ pc) to considerably larger. These sizes will *increase* in proportion to the assumed distance to NGC 5128. The larger number of ω Cen–sized clusters can be more directly appreciated by examining Figure 8, which is a plot of the second and fourth moments of the intensity distribution defined by Tyson and Jarvis (1979); these moments are dominated by the central and diffuse components of the image, respectively. As in Figure 7 the comparison is for King models of 16 sample A clusters convolved with the observed stellar PSF for an assumed distance of 3 Mpc and the indicated core radii. Two remarks should be made here. First, even though NGC 5128 is relatively nearby, the resolution of the best photographic material available to us does not allow straightforward separation of stars from clusters (see also Figs. 1 and 2). Even with PDS analysis, it would be very difficult to identify objects similar to a more typical Galactic globular cluster (with $r_c \approx 1$ pc). Second, at or beyond the canonical distance of 5 Mpc, the model curves would move closer to the line defined by stars in Figure 8. This would mean that the sample A clusters are *all* significantly larger than ω Cen, which may be another argument against distances > 5 Mpc.

One obvious feature of Figure 7 is that the clusters projected close to the center of NGC 5128 are systematically more compact than those farther out, and that the inner clusters are barely resolved at all. One possible cause for the radial trend is that the tidal forces of NGC 5128 have limited the sizes of the inner clusters. Tidal radii are expected to vary roughly as the inverse of the galactocentric distance (Innanen, Harris, and Webbink 1983). In our Galaxy, however, the core radii as well as the tidal radii depend on Galactocentric distance

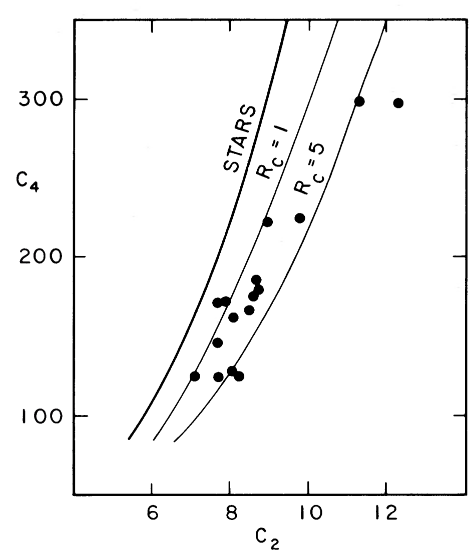

FIG. 8.—The second (*C2*) and fourth (*C4*) moments of the intensity distribution for 16 sample A clusters are compared to theoretical models for core radii of 1 and 5 pc, a tidal radius of 50 pc, and a distance of 3 Mpc (see text, § IV*b*).

(Harris and Racine 1979; van den Bergh 1983), suggesting that the cause of the size trend in NGC 5128 may be more complicated. Regardless of its cause, the systematic dependence of cluster size on position in NGC 5128 has undoubtedly introduced biases in our selection of candidates in sample A. In particular, the dependence of magnitude on position found in § IV*a* and the large extent of the cluster system compared to the halo light found in § IV*c* can both be explained, at least in part, by our preferential selection of larger clusters. This result, combined with the finding of two bright, compact clusters in sample B and the results of star counts (§ VI), reinforces the conclusion of Paper I that many clusters remain to be identified near the center of NGC 5128.

c) Distribution in NGC 5128

The NGC 5128 cluster system extends, in projection, to radial distances of at least $36(D/5)$ kpc, while of the known globular clusters in our Galaxy, only 4% have galactocentric distances greater than 36 kpc and only 9% lie beyond 21 kpc (cf. Harris and Racine 1979). These values correspond to projected distances which cluster 16 would have if NGC 5128 were at 5 and 3 Mpc, respectively. The average projected radial distance from NGC 5128 of our 17 sample A clusters is $16.0(D/5)$ kpc (9.6 kpc at $D = 3$ Mpc), and of all 27 probable clusters is $14.4(D/5)$ kpc (8.6 kpc at $D = 3$ Mpc). Ignoring projection effects, these may be compared to $\langle R \rangle = 11.1$ kpc for 112 Galactic globulars listed in Harris and Racine.[9]

If this extension is representative of the entire cluster system in NGC 5128 and if $D \approx 5$ Mpc, it is surprisingly large. Only three of the 17 sample A clusters (and five of the 27 probable clusters in the combined sample) lie within the 5$'$.5 radius that contains half of the light (van den Bergh 1976; see Fig. 6). A different representation of this trend can be seen in Figure 9, which shows a comparison of the radial distributions for our sample A clusters and the brightest globulars in the Galaxy. This comparison suggests that there are more bright clusters at large radii in NGC 5128 than in the Galaxy, particularly if the NGC 5128 distance is >5 Mpc. However, the selection effects discussed in § IV*b* (a bias against compact clusters, absorption by the dust band, and/or competition from background light) are likely to be severely affecting the distribution in Figure 9 and might explain the large apparent scale size of the NGC 5128 cluster system. In addition, tidal friction may have destroyed the most massive clusters originally lying near the center of NGC 5128. Nevertheless, the clusters which we have found near the center tend to be bright, so tidal friction is probably not dominant.

The distribution on the sky of the visually selected clusters and cluster candidates (see Fig. 3) may hint at a preferential orientation of the cluster system, in the sense that its major axis is aligned with the major axis of the outer isophotes of the spheroid of NGC 5128. A χ^2 test supports an excess of visually selected clusters in the polar regions of the galaxy at the 5% confidence level. We believe it *unlikely* that a bias in spatial distribution was introduced in selecting (from the list of candidates) specific objects for spectroscopic observation. However, the sample of confirmed clusters is so small, and the selection techniques are so subjective, that this apparent align-

[9] We exclude Pal 1 since Da Costa and Mould (1982) have found it to lie much closer than tabulated by Harris and Racine (1979).

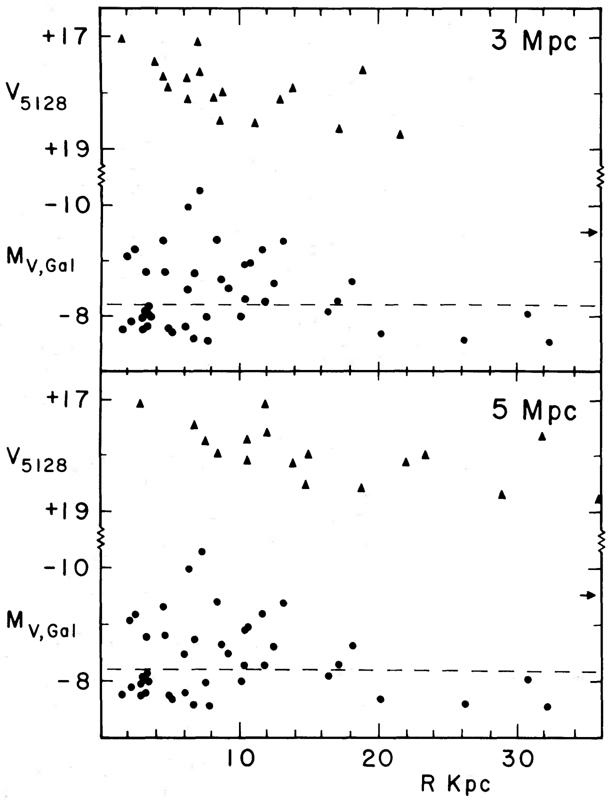

FIG. 9.—V magnitudes vs. projected distance (in kpc) for the sample A NGC 5128 globulars (*triangles*) scaled to distances of 3 and 5 Mpc are compared with M_V vs. Galactocentric distance, R, for the Galactic globular clusters (*circles*). The arrow indicates the M_V of NGC 2419, which has $R = 100$ kpc. The Galactic globulars above the dashed line exhibit the same range in magnitudes as does our sample of NGC 5128 clusters.

ment should only be regarded as a tantalizing possibility. Nonetheless we mention it because a tendency has been noted when visually surveying our plates to find more cluster suspects in the polar regions. Also, NGC 5128's outer isophotes show a marked increase in ellipticity over the inner ones (Cannon 1981). Since both the globular clusters and the faint outer isophotes are presumably representative of the oldest population in NGC 5128, it would not be surprising were they to share common spatial distributions. Indeed, the much more populous cluster system of M87 shows just such an alignment with the major axis defined by its outer isophotes (Harris and Smith 1976). Finally, we note that we have searched our velocity data for an asymmetry (rotation) by dividing the sample A clusters into northern and southern hemisphere components (with respect to the dust lane). The mean heliocentric velocities, 600 ± 55 and 660 ± 45 km s^{-1} (s.d.m.), respectively, are statistically indistinguishable. Should future studies substantiate an elongated cluster system, further attempts to elucidate its rotation properties will clearly be warranted.

d) *Strengths of Spectral Lines*

Inspection of the vidicon spectra shows that the redder clusters have stronger metallic lines than do the bluer ones. Due to the relatively short exposures (for such faint objects) and the attendant noise in the spectra, we are reluctant to attempt more quantitative analysis of line strengths at this time. However, we note that Frogel's (1980) $(V-K)_0$ color of GP's cluster (our cluster 7) led him to suggest that it had an overall metallicity similar to 47 Tucanae. From our data cluster 7 appears to be a typical NGC 5128 cluster with respect to its color and line strengths; thus, other clusters in NGC 5128 may be considerably more metal-rich than 47 Tuc. We plan to obtain spectra with higher signal-to-noise ratios to try to confirm this suggestion. Such spectra might also be used to test Cohen's (1982) intriguing, but still tentative, identification of high-velocity interstellar lines due to the NGC 5128 halo gas seen in front of two globular clusters.

V. THE MASS OF NGC 5128

a) *Determination from Globular Cluster Velocities*

Bahcall and Tremaine (1981) have recently formulated a "projected mass estimator" which they argue convincingly is better than the virial theorem which is traditionally used to estimate the mass of a massive central object embedded in a spherical system of low-mass test particles. They suggest that, in the absence of specific information on the distribution of orbital eccentricities, the best estimator is that given by their equation 23, namely

$$M_0 = \left(\frac{24}{\pi G N}\right) \sum^{N} v_{zi}{}^2 R_i \,, \tag{1}$$

where N is the number of test particles (globular clusters), v_{zi} is the difference in systemic and observed radial velocities for the ith particle, and R_i is the projected radial distance of that particle. Subsequent study by Tremaine (1981) of the form of the projected mass estimator required for a spherical system in which the mass density is assumed to follow the light yields a multiplicative factor of 64 for equation (1) rather than 24. We adopt the higher value for derivation of the NGC 5128 mass from the globular cluster velocities of Table 3.

To undertake the calculation of the v_{zi}'s we require an appropriate value for the systemic velocity. Many values, spanning a range of ≈ 190 km s^{-1}, are available in the literature (see Table 4). Graham (1979) tentatively suggests that this lack of agreement may arise from contamination by night sky lines in the earlier optical work. Another factor may, however, also be involved. For the velocities determined since 1970, the mean is 549 ± 6 km s^{-1}; for the seven earlier papers the mean is 489 ± 22 km s^{-1}. Sérsic and Carranza (1969), Graham (1979), and Marcelin *et al.* (1982), among others, have graphically illustrated NGC 5128's complex velocity field, and its large associated gradients in the vicinity of the dust band. Perhaps variations in exact slit placement and larger slit sizes in some of the earlier work combined with the velocity gradients to produce a part of the spread seen in Table 4. We may sidestep the issue of uncertainties in the NGC 5128 velocity by adopting the mean radial velocity of our globular clusters as the systemic velocity. Such values, calculated for various subsets of our data and given in Table 5, lie above the most recent values given in Table 4 for the galaxy, itself. As discussed in § III and the Appendix, we believe our SIT velocities to be on the system defined by the Galactic globular clusters. Unless some systematic error has been inadvertently introduced (and observations of com-

TABLE 4

ESTIMATES OF THE SYSTEMIC VELOCITY FOR NGC 5128

$V_{r,\odot}$ Optical	$V_{r,\odot}$ Radio	Features	Reference
450		Em.: [O II] 3727, Hβ, Hγ	Baade and Minkowski (1954)
468 ± 40		Em. + Abs. Lines	Humason, Mayall and Sandage (1956)
605		Em.: Hα, [N II] 6584	Burbidge and Burbidge (1959)
434 ± 75		Abs.: Ca II + other Absorption Lines	Evans and Harding (1961)
484:		Abs. + [O II] 3727 em.	
630		Em.: [O II] 3727	Burbidge and Burbidge (1962)
470 ± 50		Abs.: Ca II H, Hδ, Fe I 4383	
465 ± 50		Em.: Hα (Fabry-Perot)	Sérsic and Carranza (1969)
462 ± 25		Em.: [O II] 3727, Hα, [N II] 6548	Sérsic (1969)
420::		Abs.: Ca II K, Hδ, G-band	
	563	Abs.: 21-cm, profile mid point	Roberts (1970)
	551	Abs.: 21-cm, strongest component	
508 ± 11		Em.: Hα	Kunkel and Bradt (1971)
475 ± 47		Abs.: Na D	
	530	Em.: 21-cm	Whiteoak and Gardner (1971)
	550	Abs.: 21-cm, strongest component	
	546 ± 3	Abs.: H_2CO, avg. of 3 components	Gardner and Whiteoak (1976a)
	551.1	Abs.: 21-cm, strongest component	Gardner and Whiteoak (1976b)
	551.8	Abs.: H_2CO, strongest component	
	551	Abs.: OH, strongest component	
548 ± 5		Em.: Hα, [N II] 6548, 6584, [O I] 6300, 6364, [S II] 6716, 6731	Graham (1979)
536 ± 30		Abs.: Fe I 4383, Hβ, Mg I 5170, 5183	
551.4		Em.: Hα	Whiteoak and Gardner (1979)
557.6		Abs.: Na D	
607 ± 18		Em.: [O II] 3727, Hβ, [O III] 4959, 5007	Appenzeller and Möllenhoff (1980)
559 ± 24		Abs.: Ca II H,K, Ca I 4226, Fe I 4271, 4383	
541 ± 8		Em.: Hα, [N II] 6584	Rodgers and Harding (1980)
602 ± 38		Em.: Hβ, [O III] 4959, 5007, [N II] 6548, 6584 Hα, [S II] 6717, 6731	Möllenhoff (1981)
545 ± 5		Em.: Hα (Fabry-Perot)	Marcelin et al. (1982)
	553.2	Abs.: 21-cm (VLA)	van der Hulst, Golisch and Haschick (1983)

parably faint stars in ω Cen argue against this possibility), an intriguing difference of $\approx 90 \pm 30$ km s^{-1} between the systemic velocity of NGC 5128 and the mean velocity of our sample of globular clusters is suggested.

We therefore carried out our mass calculations using for the systemic velocity (1) the mean cluster velocity determined for each sample of clusters and (2) Graham's $v_{\text{systemic}} = 548$ km s^{-1}. The velocity dispersions of the 19 clusters are found to be $\sigma = 140$ km s^{-1} relative to their mean velocity and $\sigma = 165$ km s^{-1} relative to Graham's velocity. Regardless of the exact sample or systemic velocity adopted, the mass of NGC 5128 is found from equation (1) (modified) to be $\approx 1.6 \times 10^{12}$ $(D/5)$ $M_\odot$. Since all of the globular clusters observed in the present program lie within 24′.5 of the center of NGC 5128, this value refers to the mass interior to $36(D/5)$ kpc. The results presented in Table 6 separately for the 1980, 1981, and the combined 1980–1982 sample are insensitive to the exact sample and systemic velocity chosen.[10] [For

TABLE 5

MEAN RADIAL VELOCITIES FROM THE NGC 5128 GLOBULAR CLUSTERS

Sample	N	$\langle V_{r,\odot} \rangle$ (km s^{-1})	σ_m (km s^{-1})
1980	5	608	37
1981	15	633	40
1980 + 1981	17	630	36
1980 + 1981 + 1982	19	637	32

[10] Although an earlier report on this work (Hesser *et al.* 1981) claimed that Tremaine's (1981) formulation was used for the mass calculations, equation (1) was, in fact, employed, thereby accounting for the difference of a factor of 2.7 between the masses in Table 6 and those given in the earlier reference.

TABLE 6

NGC 5128 MASS ESTIMATES FROM THE GLOBULAR CLUSTER RADIAL VELOCITIES

		MASS [$\times 10^{11}$ $(D/5)$ $M_\odot$]	
SAMPLE	N	$\langle V_{\text{Globulars}} \rangle$[a]	$\langle V_{\text{Graham}} \rangle$[b]
1980	5	3.4	9
1981	15	17	16
All	19	14	15
$d < 10'$	11	5.6	11
$d > 10'$	8	25	20

[a] v_{systemic} taken to be the mean velocity of the particular sample of globular clusters.

[b] v_{systemic} is taken from Graham 1979.

comparison with the results from the projected mass estimator, we note that the mass found by the standard virial theorem method (cf. Paper I) is $\approx 3 \times 10^{11}$ $(D/5)$ $M_{\odot}$. Similar differences in mass estimates for other systems analyzed by the two techniques were reported by Bahcall and Tremaine (1981).] Elimination of specific objects, such as cluster 26, produced only minor differences from the values given in Table 6. Our calculations are thus in accord with Bahcall and Tremaine's (1981) remark that their projected mass estimator is relatively stable when applied to small numbers of test particles.

According to van den Bergh (1976) the integrated magnitude of NGC 5128 (corrected for both foreground *and* internal absorption) is $V_0 = 5.86$. Combining this with $M \approx 1.6 \times 10^{12}$ $(D/5)$ $M_{\odot}$ (see Table 6) yields $M/L_V \approx 16(5/D)$ in solar units. This lies within the range $5.4 < M/L_V < 21.1$ ($H = 75$ km s^{-1} Mpc^{-1} assumed) of values that Faber and Gallagher (1979) find for other early-type galaxies. However, it is possible that our value is not strictly comparable to their tabulated ones for two reasons. First, our clusters sample the mass further into the halo than other optical techniques; and, second, the most appropriate value of the coefficient to be used in equation (1) is debatable.

Clusters more distant than 10′ consistently yield a higher mass estimate than the nearer ones, as shown by the last two rows of Table 6. Although expected, such a result naturally leads one to ask if we have sampled essentially all the mass of NGC 5128 with these cluster velocity measurements.

b) Determination from Velocities of Galaxies in the NGC 5128/5236 Group

Inspection of catalogs of radial velocities of galaxies shows a loose concentration of objects with Galactocentric velocities $V_0 < 600$ km s^{-1} in the Centaurus/Hydra area (cf. Table 7). Six members of this group are listed by de Vaucouleurs (1975). Eight additional dwarf galaxies in this region were found on SRC Schmidt plates by Webster *et al.* (1979). Furthermore Allen (1974) finds that NGC 5408, which was originally classified as a Be star, is in fact an intergalactic H II region with $V_0 = +304$ km s^{-1} located 7° from NGC 5128. Finally Fairall (1981) regards the faint elliptical NGC 5237 situated only 2°3 from NGC 5128 as a foreground Local Group member. Its radial velocity, $V_0 = 117$ km s^{-1}, is, however, comparable to the value $V_0 = 141$ km s^{-1} which Webster *et al.* obtain for UKS 1346−358. NGC 5237 will therefore be tentatively regarded as a member of the NGC 5128/5236 Group.[11] UKS 1332−453 (Dottori and Fourcade 1973; Graham 1978) might be a background object, on the basis of both its large radial velocity $V_0 = +607$ km s^{-1} and its 21 cm line width $\Delta V = 152$ km s^{-1}.

The distribution on the sky of the objects listed in Table 7 is shown in Figure 10. The group exhibits significant subclustering with major concentrations surrounding the peculiar elliptical NGC 5128 and the supergiant spiral NGC 5236 = M83. Some cluster members may remain undiscovered due to Galactic absorption at $b < 10°$. The recently discovered galaxy A1409−65 (Freeman *et al.* 1977) at $l = 311°3$, $b = -3°8$ may be an example of such an object. Our calculations do not include NGC 5206 which Caldwell (1983) has recently suggested as a possible member of the NGC 5128 Group.

For all 17 galaxies listed in Table 7 $\langle V_0 \rangle = +314 \pm 28$ km s^{-1} with a dispersion $\sigma = 115$ km s^{-1}. If UKS 1332−453 is excluded, the remaining 16 galaxies yield $\langle V_0 \rangle = +295 \pm 22$ km s^{-1} and $\sigma = 90$ km s^{-1}. These mean values are very close to those of the two major cluster galaxies NGC 5128 and NGC 5236 for which $V_0 = +318 \pm 30$ km s^{-1} and $V_0 = +329 \pm 10$ km s^{-1}, respectively.

[11] If NGC 5237 is, in fact, a member of the Local Group, it should be resolved on red plates obtained with large reflectors.

TABLE 7

PROBABLE MEMBERS OF THE NGC 5128/5236 GROUP

Galaxy	α(1950)	δ(1950)	l	b	V_0 (km s^{-1})[a]	r
UKS 1243−336	12ʰ43ᵐ3	−33°34′	301°7	+29°0	361 ± 5	12°0
NGC 4945	13 02.5	−49 12	305.3	+13.3	322 ± 10	7.5
NGC 5068	13 16.2	−20 47	311.5	+41.4	401 ± 70	22.0
NGC 5102	13 19.1	−36 22	309.7	+25.8	266 ± 15	6.5
NGC 5128	13 22.5	−42 46	309.5	+19.4	318 ± 30[b]	0.0
UKS 1324−412	13 24.7	−41 13	310.2	+20.9	298 ± 5	1.6
UKS 1332−453[c]	13 32.5	−45 25	310.8	+16.7	607 ± 5	3.3
NGC 5236	13 34.2	−29 37	314.6	+32.0	329 ± 10	13.4
UKS 1334−278	13 34.5	−27 48	315.1	+33.7	414 ± 5	15.2
NGC 5237	13 34.7	−42 36	311.9	+19.2	117 ± 15[d]	2.3
NGC 5253	13 37.1	−31 23	314.9	+30.1	204 ± 3	11.1
NGC 5264	13 38.8	−29 40	315.8	+31.7	300 ± 10	13.5
UKS 1342−416	13 42.0	−41 37	313.5	+19.9	335 ± 5	3.9
UKS 1346−358	13 46.4	−35 49	315.8	+25.4	141 ± 4	8.4
NGC 5408	14 00.2	−41 08	317.1	+19.5	304 ± 10[e]	7.2
UKS 1424−460	14 24.8	−46 05	319.8	+13.4	204 ± 6	11.6
UKS 1457−480	14 57.7	−48 06	324.1	+9.2	412 ± 4	17.5

[a] $V_0 = V + 300 \sin l \cos b$.
[b] Radial velocity from Graham 1979.
[c] Membership doubtful (Graham 1978).
[d] Radial velocity from Fairall 1981.
[e] Radial velocity from Allen 1974.

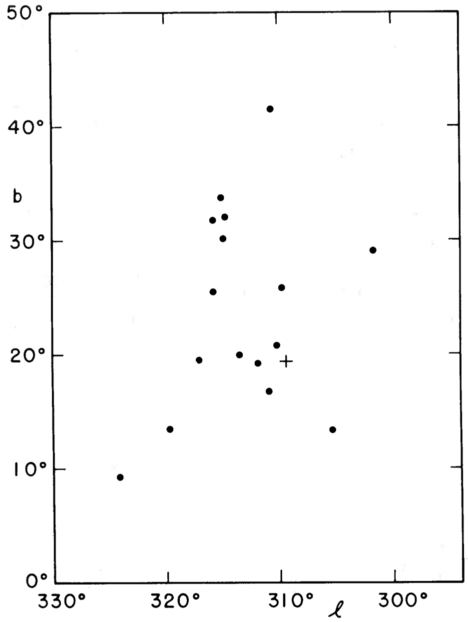

FIG. 10.—Distribution of 17 probable members of the NGC 5128/5253 group on the sky. NGC 5128 is marked by a cross.

Although Webster *et al.* (1979) concluded that the NGC 5128/5236 Group is probably stable, they were unable to assess its state of relaxation. (Earlier studies, which lacked Webster *et al.*'s dwarf galaxies, suggested that the Centaurus Group was marginally unstable [Rood, Rothman, and Turnrose 1970; Materne and Tammann 1974].) The fact that the group exhibits pronounced subclustering indicates that it is not yet "virialized." This makes the determination of its mass from the observed radial velocities of its members even more hazardous than usual. Specifically, the orbital characteristics of the galaxies being used as test particles and, hence, the numerical coefficient to be used in equation (1) are problematical.

We have adopted the following three assumptions for the calculations of masses summarized in Table 8; (1) for calculation of v_{zi}^2 in equation (1), we use $v_z = 0$ for NGC 5128; (2) the galaxies in the NGC 5128 subgroup have isotropic velocities (i.e., a coefficient of 16 in eq. [1]); and (3) a distance to this group of 5 Mpc. Detailed discussions of the actual distance to this group are given by de Vaucouleurs (1979) and by Webster *et al.* (1979), while the distance to NGC 5128 itself is discussed further in § VI*b*, below. Adoption of the second assumption yields masses that represent lower limits, but which are already larger than those derived from the globular clusters. If the galaxy orbits are linear, the quoted masses have to be multiplied by a factor of 2. If (as was done for the globulars) no assumptions are made about their orbits and Tremaine's (1981) modification is employed, the masses in Table 8 must be multiplied by 4. In view of the lack of a strong central mass concentration in the Centaurus Group, the latter value may be more appropriate. Our estimates of the total mass of the NGC 5128/5236 Group lie in the range 8–25 $\times 10^{12}$ $(D/5)\,M_\odot$. Comparison with the value derived from the globulars, $M \approx 1.6 \times 1012$ $(D/5)\,M_\odot$, suggests that NGC 5128 has a massive halo that extends beyond the distances sampled by the globular clusters identified in Fig. 3. Alternatively, much of the mass in the NGC 5128/5236 cluster might consist of more smoothly distributed intracluster material.

VI. NEW RESULTS FROM STAR COUNTS CONCERNING THE SIZE OF THE NGC 5128 GLOBULAR CLUSTER SYSTEM AND THE DISTANCE TO NGC 5128

a) *Counts on UK Schmidt Plate J3986*

In Paper I we used star counts made on the SRC Southern Sky Survey film J270 to estimate the excess population of starlike objects in the vicinity of NGC 5128. However, this galaxy appears near the corner of J270. Thus it is impossible to make circularly symmetric counts beyond $\approx 28'$, and vignetting from the calibration wedge presumably adversely influences portions of the counts at smaller radii. Due to the surprisingly (cf. § I) large number of excess starlike objects (≈ 600) found, those counts suggested that a redetermination with new plate material was desirable for at least two reasons. First, in order to smooth out the possible statistical fluctuations associated with the clustering of galaxies in the area sampled for determining the background level, a very large area should be surveyed. Second, if the distance of NGC 5128 is < 5 Mpc, it is important to sample at large radii in order to have a background measurement free of star clusters (Hanes 1980). To that end we made two independent sets of counts of starlike objects on a film copy of UK Schmidt plate J3986 centered on NGC 5128 (kindly provided by the Royal Observatory, Edinburgh Photolabs through Dr. R. D. Cannon).

J3986 reaches $J > 22.0$ mag according to a visual comparison with the Pickering–Racine secondary images on plate P5254 (cf. Table 2). Independent counts using different reseaux were made of J3986 by van den Bergh and by Hesser. For the former set, the counts were made through a low-power eyepiece in 25 rings of width 66″.0 centered on this galaxy (cf. Table 9). Background counts were obtained in four areas, each of 606 arcmin^2, centered $\approx 77'$ north, south, east, and west of the galaxy center. Ring sectors of 30° width were counted alternately inward and outward. Nonstellar images (which amounted to perhaps 20% of the total) were not

TABLE 8

MASS ESTIMATES FOR NGC 5128 SUBCLUSTER

Sample	$R < 4°.0$[a]	$R < 8°.0$[b]
Mass including 1332−453	7.6×10^{12} $(D/5)\,M_\odot$	5.0×10^{12} $(D/5)\,M_\odot$
Mass excluding 1332−453	2.4×10^{12} $(D/5)\,M_\odot$	1.7×10^{12} $(D/5)\,M_\odot$

[a] Corresponds to linear radius $R = 350$ $(D/5)$ kpc.
[b] Corresponds to linear radius $R = 700$ $(D/5)$ kpc.

TABLE 9

STAR COUNTS BY VAN DEN BERGH IN RINGS SURROUNDING NGC 5128

Ring	$\langle r \rangle$ (arcmin)	Count	σ	m.e.
4	4.4	186:[a]	6.12:	± 0.45
5	5.5	240	6.32	± 0.41
6	6.6	281	6.16	± 0.37
7	7.7	321	6.03	± 0.34
8	8.8	367	6.04	± 0.32
9	9.9	423	6.18	± 0.30
10	11.0	468	6.16	± 0.28
11	12.1	488	5.84	± 0.26
12	13.2	500	5.48	± 0.25
13	14.3	538	5.45	± 0.23
14	15.4	587	5.42	± 0.23
16.5–27.5	15–25	9051	5.41	± 0.06

[a] Counts uncertain because of high background density.

TABLE 10

COUNTS BY QUADRANTS OF TABLE 9

Position Angle	Net Count
0°–90°	144 ± 36
90°–180°	0 ± 34
180°–270°	-21 ± 33
270°–360°	202 ± 37

counted. The surface densities and their *formal* mean errors (expressed in stars per arcmin^2) are found to be N = 5.41 $\pm$ 0.09, E = 5.61 $\pm$ 0.10, S = 6.24 $\pm$ 0.10, and W = 5.48 $\pm$ 0.10 in the sky comparison areas. The average, $\langle \sigma \rangle = 5.68 \pm 0.05$, is significantly *higher* than the $\sigma = 5.41 \pm 0.06$ that is obtained for an annulus with $17.05 < r(\text{arcmin}) < 28.05$ (rings 16–25) surrounding NGC 5128. The most likely explanation for the observed variation in the surface density of starlike images is that the counts have been contaminated by galaxies, which are known to have a clumpy distribution. Visual inspection of plate J3986 supports the suggestion that there is a particularly high concentration of distant galaxies in the southern comparison area. As a result, the real errors of the net counts may be significantly larger than their quoted mean errors. An additional (but probably small) uncertainty is introduced by the fact that the absorption in the NGC 5128 field may be slightly patchy.[12]

In view of the observed variations in σ_{sky} as a function of quadrant, it seems safest to use counts in rings surrounding NGC 5128 to derive the number of globular clusters surrounding this galaxy. From the data in Table 9, the excess over background (which is presumed to be due to globular clusters) is found to be 325 ± 79 s.e. Extrapolating the observed surface densities to $r = 0$ yields a total cluster population of 475 ± 120 (estimated error), a value which is in good agreement with that of Paper I from the slightly deeper counts in SRC field J270. A breakdown of the cluster counts in rings 4–14 into quadrants yields the values listed in Table 10. The fact that all of the clusters appear to be located on the north side of NGC 5128 is most likely due to a gradient in the background density of galaxies across the field.

From the counts in Table 9 there is no statistically significant excess of clusters outside ring 14, i.e., beyond 16′ or $23(D/5)$ kpc. Although this is considerably smaller than the ≈ 100 kpc radius of the Galactic globular cluster system, it is not particularly bothersome. Less than 4% of the Galactic globulars have $R > 35$ kpc, and many of the more distant ones are sparsely populated, low-luminosity clusters.[13] Furthermore, three clusters, clusters 1, 16, and 27 (cf. Table 3), lie in the region that was used to determine the background in Table 9, showing that some distant clusters do, indeed, exist. For these reasons, and the statistical uncertainties associated with the entries of Table 9, we conclude that variations in the background density of galaxies severely limits the accuracy with which the total cluster population can be determined for NGC 5128.

The second set of counts on J3986 (cf. Table 11) were made by Hesser using a 10 × binocular microscope, and the same reseaux and precepts described in Paper I. The background computed for ring 20 is very similar to that found by van den Bergh. However, the counts of Table 11 do suggest a (statistically insignificant) increase over background in ring 4 at $\langle R \rangle = 22'$, rather than the significant decrease (compared with the sky areas) seen in Table 9 for radii 16$'$.5–27$'$.5. The counts in Table 11 also confirm the high background toward the south of NGC 5128, as well as the importance of variations in the background counts. By adopting $\sigma = 5.78 \pm 0.05$ (m.e.) for the background[14] we may estimate, by linear extrapolation of the data for rings 2–4 to $R = 0$, a total excess population of starlike objects associated with NGC 5128 of $\approx 440 \pm 110$ (estimated error). This result[15] is in excellent agreement with that derived earlier from the data of Table 9.

[12] Evidence for this is provided by deep exposure plates of this region (Cannon 1981). Some of the material visible on such plates is undoubtedly faint foreground "high latitude cirrus" illuminated by the Galactic plane, while the rest may be faint extensions of the optical light of NGC 5128, itself. Evans and Harding (1961) also found patchiness in their star counts to $B > 19$ in a $24' \times 36'$ area centered on NGC 5128.

[13] Furthermore, our visual selection procedures are primarily sensitive to rather luminous and large clusters, and it seems improbable that we would find a high percentage of remote, ordinary NGC 5128 globulars when we must discriminate against a significant foreground-star and background-galaxy population in that direction.

[14] Interpretation of the star counts may also be limited by uncertainties in the limiting magnitude adopted. Models of the Galactic halo and of the surface densities of distant galaxies provide an independent method for examining the limiting magnitude. Predictions of stellar surface densities for $9 < J < 25$ and $A_J = 0.4$ in the direction of NGC 5128 ($l = 309^\circ.5$, $b = +19^\circ.9$) were kindly calculated for us by Pritchet (1983*b*) based on Galaxy models described elsewhere (Pritchet 1983*a*). From a study of 12 Galactic halo fields, Jarvis and Tyson (1981) have derived a relation for the dependence of the surface densities of distant galaxies on limiting magnitude. The resulting surface densities of foreground and background objects are shown in Table 12. For a limiting magnitude of $J = 22$, the predicted total surface density of stars plus galaxies ($\sigma = 5.41$) is in remarkably good agreement with the mean observed surface densities discussed earlier. This suggests that our estimate of $J_{\text{lim}} = 22$ is, at least, a reasonable one. However, we note that the presence of large numbers of galaxies in the direction of NGC 5128 has left us with the qualitative impression that the surface density of galaxies predicted by the Jarvis and Tyson relation may be an underestimate of the value appropriate for the NGC 5128 field.

[15] We increased the net counts by 18/16 to account for the missing sectors when computing the cumulative counts.

TABLE 11

STAR COUNTS ON J3926 (HESSER)

	Ring	20		4		3		2	
	$\langle R$ (mm, arcmin)$\rangle$	85, 96		20, 22		11, 12		6.5, 7.3	
	Sector Area (mm^{-2})	124		25.9		15.8		9.4	
	Sector	N	σ	N	σ	N	σ	N	ρ
N	1	829	5.23	170	5.42	135	6.75	81	6.84
	2	848	5.43	190	6.06	135	6.73	66	5.58
	3	840	5.38	205	6.53	116	5.80	91	7.69
	4	939	6.02	177	5.64	117	5.85	76	6.42
	5	847	5.43	200	6.38	114	5.70	72	6.08
E									
	6	905	5.80	197	6.28	125	6.25	75	6.34
	7	1013	6.49	186	5.93	132	6.60	79	6.67
	8	923	5.91	202	6.44	142	7.10	68	5.74
	9	1052	6.74	195	6.22	137	6.85	75	6.34
S	10	1024	6.56	171	5.45	130	6.50	71	6.00
	11	978	6.27	188	5.99	112	5.60	86	7.27
	12	1048	6.71	192	6.12	131	6.55	58	4.90
	13[a]	...	...	...	...	...	...	...	...
	14[a]	...	...	...	...	...	...	...	...
W									
	15	817	5.23	191	6.09	119	5.95	62	5.24
	16	795	5.09	173	5.51	121	6.05	72	6.08
	17	795	5.09	177	5.64	139	6.95	82	6.93
	18	781	5.00	171	5.45	126	6.30	74	6.25
	Total	14434		2985		2031		1188	
	m.e.	0.01		0.02		0.02		0.03	
	σ (*/arcmin^2) $\pm$ m.e.:								
	All	5.78 ± 0.05		5.95 ± 0.11		6.35 ± 0.14		6.27 ± 0.18	
	Sectors 17–2 $\sim$ N	5.21 ± 0.09		5.64 ± 0.21		6.69 ± 0.29		6.40 ± 0.33	
	3–6 $\sim$ E	5.66 ± 0.10		6.21 ± 0.22		5.90 ± 0.27		6.63 ± 0.37	
	7–10 $\sim$ S	6.43 ± 0.10		6.01 ± 0.22		6.77 ± 0.29		6.19 ± 0.36	
	11–16 $\sim$ W	5.83 ± 0.10		5.93 ± 0.22		6.04 ± 0.27		5.87 ± 0.35	

[a] Unfortunately the reseaux were removed before sectors 13 and 14 could be counted.

b) Observed and Expected Number of Globulars and the Distance to NGC 5128

In their original paper Graham and Phillips (1981) called attention to the unusually high luminosity of their cluster, and de Vaucouleurs (1980) also remarked upon possible consequences of this for the distance of NGC 5128 itself. In Paper I we showed that the first five clusters identified implied either than NGC 5128 is closer than the 5 Mpc usually assumed for it (Burbidge and Burbidge 1959) or that its brightest clusters are unusually luminous. Harris and Racine (1979) showed that the luminosity function of globular clusters in the Local Group, which is, of course, dominated by the Galaxy and M31, is well represented by a Gaussian with $\langle M_V \rangle = -7.3$ mag and $\sigma = 1.2$ mag. *Assuming* a similar luminosity function for the NGC 5128 globulars, one can predict the expected number of clusters that should be visible down to various limiting magnitudes. In Table 13 and Figure 11 these predicted numbers of clusters are compared with the observed number of confirmed globulars under the assumptions that: (1) the total number of globular clusters brighter than $J = 22$ associated with NGC 5128 is ≈ 600 (cf. Paper I and the previous section); and (2) the foreground reddening is $E(B-V) = 0.10$ mag (van den Bergh 1976).

For $V < 18.0$ mag the globular cluster data give a best fit apparent distance modulus $(m - M)_V = 27.7$ mag, which yields a distance of 3.0 Mpc. This estimate falls near the lower

TABLE 12

SURFACE DENSITY OF STARS, GALAXIES, AND GLOBULAR CLUSTERS IN THE NGC 5128 FIELD

$J_{\rm lim}$	σ_s	σ_g	σ_{s+g}	$\sigma_\oplus$	$\sigma_\oplus/\sigma_{s+g}$
17.0	0.46	0.00	0.46	0.0	0
18.0	0.89	0.01	0.90	0.02	0.022
19.0	1.57	0.02	1.59	0.15	0.094
20.0	2.53	0.05	2.58	0.62	0.240
21.0	3.66	0.07	3.73	1.52	0.408
22.0	5.04	0.37	5.41	2.41	0.445
23.0	6.79	1.01	7.80	2.87	0.368
24.0	9.06	2.81	11.87	2.99	0.252

TABLE 13

COMPARISON OF OBSERVED AND PREDICTED NUMBER OF GLOBULARS BRIGHTER THAN V

V	N (observed)	N ($D = 3$ Mpc)	N ($D = 5$ Mpc)
17.00	0	1.4	0.0
17.25	2	2.6	0.1
17.50	4	4.6	0.3
17.75	8	8.1	0.5
18.00	11	14	1.0
18.25	14	22	2.0
18.50	15	34	3.6
18.75	20	51	6.4

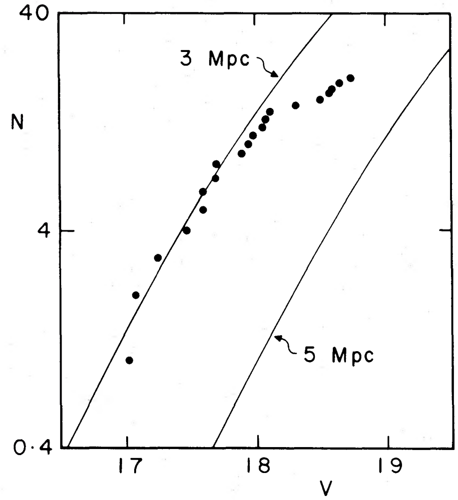

FIG. 11.—The cumulative luminosity function of the confirmed globular clusters is compared with a model based on a total cluster population of 600 and reddening of 0.10 mag for the distances indicated.

boundary of the range of modern estimates ($D = 3.7$ Mpc—de Vaucouleurs 1979, 1980; $D = 5$ Mpc—Burbidge and Burbidge 1959; and $D = 8.5$ Mpc—Sandage and Tammann 1974; see also Webster *et al.* 1979). Inasmuch as our spectroscopic observations do not extend faint enough to see the peak in the luminosity function of the NGC 5128 globular clusters, it could be argued (cf. Tammann 1983) that the distance implied by the comparison in Figure 11 is rather imprecise due to uncertainties in the estimates of the total cluster population. While agreeing in principle that it is vital to extend our study to much fainter magnitudes, as we are attempting to do, we also note the following.

The deficiency of globulars with $V > 18.1$ mag in Table 13 and Figure 11 is, no doubt, due to incompleteness in the present sample of confirmed clusters. Once that incompleteness is properly accounted for, a larger distance modulus may emerge. In contradistinction, however, if our data for $V < 18.0$ mag are also still somewhat incomplete, then $D < 3.0$ Mpc. Since, of our clusters, the third brightest in V (cluster 23) was discovered during our 1982 spectroscopic observations of the complete B sample of photometrically selected candidates, *some incompleteness must still exist among the brightest confirmed clusters*, as well.

If NGC 5128 lies at a distance of ≈ 3 Mpc, our star counts have passed the peak of the cluster luminosity function. As a result deeper star counts sampling the faint tail of the cluster luminosity function would not add much information about the distance. Were we to renormalize our cluster population estimates arbitrarily to a total population of 2000 clusters, the distance implied by a comparison such as that of Figure 11 would be ≈ 4 Mpc. There exists some point beyond which increasing the total cluster population will lead to a surface density of clusters sufficiently high that NGC 5128's cluster system would become obvious to visual inspection. We remind the reader that, quite unlike M87's cluster system, the existence of NGC 5128's system is not obvious during careful inspection of deep plate material (cf. Sérsic 1969; van den Bergh 1979; de Vaucouleurs 1979; Paper I; and the previous section).

TABLE 14

SURFACE DENSITY OF GLOBULARS AT DIFFERENT ASSUMED GALAXY DISTANCES

D (Mpc)	n[a]	σ[b]
1	699	0.32
2	660	1.20
3	591	2.41
4	438	3.18
5	330	3.74
7	172	3.82
10	64	2.90
15	14	1.32
20	3	0.54

[a] Number of clusters brighter than $J = 22.0$.

[b] Mean surface density of globulars within radius containing half of all clusters.

This concern has led to asking where the maximum contrast in surface density of globulars versus other foreground and background objects might be expected to occur. We examined this question in a somewhat general fashion while adopting several assumptions appropriate to NGC 5128, namely: (1) a total population of 700 clusters; this number was chosen to yield the observed number of ≈ 600 objects brighter than $J_{\rm lim} \approx 22$ for an assumed distance of 3 Mpc; (2) that half of the clusters lie within $r_{1/2} = 6.25$ (3/D) arcmin (cf. Paper I); and (3) that the clusters follow the same Gaussian luminosity function adopted earlier (i.e., $\langle M_J \rangle = -6.8$, $\sigma = 1.2$). In Table 14 we give the total number of clusters and the average surface density of clusters within $r_{1/2}$ and brighter than $J = 22$ for various assumed galaxy distances. These results are shown in Figure 12 along with σ_{s+g} already described and given in Table 12. From Figure 12 we can see that the contrast between clusters and the background plus foreground is good for $3 < D < 13$ Mpc; the optimum occurs at $D \approx 6.5$ Mpc. With fainter plate limits the optimum

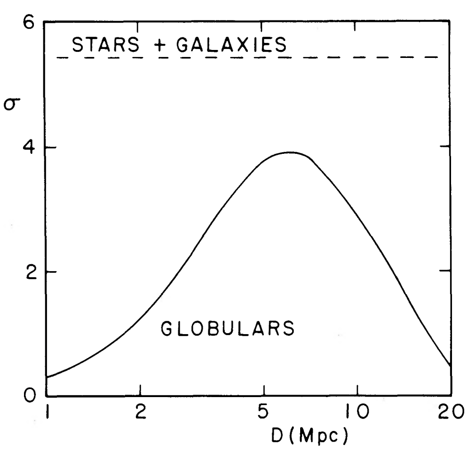

FIG. 12.—The mean surface density of globulars (in clusters arcmin^{-2}) within $r_{1/2}$ as a function of assumed galaxy distance. The figure shows good contrast between clusters and background plus foreground for $3 < D < 13$ Mpc. Optimum contrast is seen to occur for a galaxy distance of $D \approx 6.5$ Mpc.

contrast for globular cluster counts is shifted to greater distances.

The fact that there is an optimum distance for detection of a globular cluster system is due to two factors. First, for nearby galaxies the system is spread over a larger area of the sky and is thus harder to separate from the field, particularly at low Galactic latitudes. Second, for more distant galaxies, the clusters themselves are fainter, hence fewer are detectable above the plate limit.

Using an assumed distance of 3 Mpc for NGC 5128 we can also calculate the surface density for the cluster system. These numbers are given in the final column of Table 14 and plotted in Figure 13 along with σ_{s+g}. Here we can see that the maximum contrast between the surface density of globulars and the foreground plus background density is attained at $J \approx 22$. This suggests that SRC plate J3986 (cf. § VI) is close to being optimally suited to studies of the structure and total population of the NGC 5128 globular cluster system.

In summary, the properties of the NGC 5128 globular cluster system, as presently explored (namely the cumulative luminosity function as well as the M_V's and the inferred sizes of the brightest clusters), seem most consistent with a distance of 3 ± 0.5 Mpc to the galaxy rather than the higher values usually quoted. We caution, however, that our reasoning depends upon an assumption which is difficult to test, e.g., that the NGC 5128 globular cluster system has a Gaussian luminosity function similar to the luminosity function of the globular cluster systems associated with Local Group galaxies.

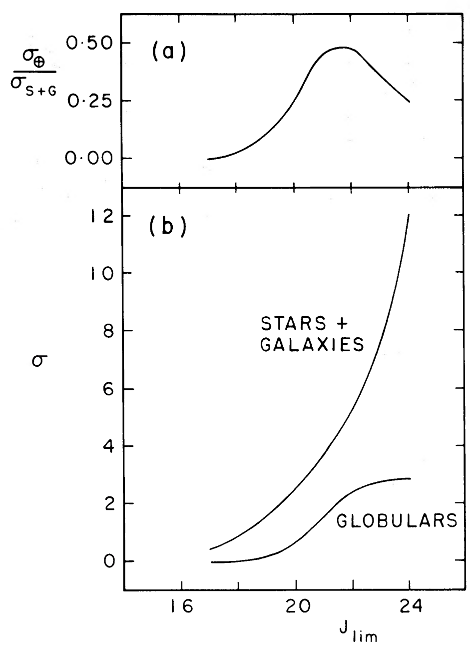

FIG. 13.—Comparison (for an assumed distance of 3 Mpc) between the mean surface density of globulars within 6'.25 of NGC 5128 and the total background galaxy plus foreground star density. Fig. 13*a* plots the ratio of the surface density of the globulars, $\sigma_\oplus$, to the combined surface densities of stars plus galaxies, σ_{s+g}, while Fig. 13*b* plots the individual surface densities. The fact that the ratio $\sigma_\oplus/\sigma_{s+g}$ is less than 1 emphasizes the difficulties of detecting the cluster system. The figure shows that the constrast between clusters and the background plus foreground is greatest for $J_{\rm lim} \approx 22$. The rapid rise in σ_g for $J > 22$ is due to the rapid increase in the contribution of galaxies to the total surface densities at faint magnitudes.

c) *Application of the New Centaurus Group Distance to the Luminosity of SN1972e in NGC 5253*

One of the numerous potential implications of the new distance estimate to NGC 5128 concerns the determination of the M_B value for SN 1972e, a Type I supernova in NGC 5253. Since NGC 5128 and NGC 5253 are both members of the same group, the newly determined distance to NGC 5128 should also apply to NGC 5253. Fitting the photoelectric B magnitudes measured by Ardeberg and de Groot (1973) for this supernova to the mean light curve of fast Type I supernova by Barbon, Ciatti, and Rosino (1973) yields $B(\max) = 8.35 \pm 0.10$ (estimated fitting error).[16] Combining this with $(m - M)_0 = 27.39 \pm 0.36$ (based on $D = 3$ Mpc) and $A_B = 0.40 \pm 0.03$ (based on the reddening discussion of van den Bergh 1976) gives $M_B(\max) = -19.45 \pm 0.4$. Comparison of this value of $M_B(\max)$ (which is > 1 mag fainter than would be estimated using $D = 5$ Mpc) with $B(\max)$ of accurately observed Type I supernovae in ellipticals beyond the Local Supercluster should be able to provide a determination of the global value of the Hubble parameter.

VII. SUMMARY

Our visual selection techniques have proven remarkably efficacious, and it seems likely that many more clusters will be found by this approach. The spectroscopically confirmed clusters show a wide range in $B-V$ color and imply that some NGC 5128 globular clusters may be significantly more metal-rich than 47 Tuc. Furthermore, the redder clusters lie nearer (in projection) to NGC 5128 than the bluer ones. Selection effects (discussed in § IV) probably contribute significantly to the observed spatial distribution of the confirmed clusters. However, we argue that they do not seem to account for a *possible* alignment of the major axis of the cluster system with that defined by the outer isophotes of NGC 5128, itself. From the globular cluster velocities, we estimate the mass of NGC 5128 to be $\approx 1.6 \times 10^{12}$ $(D/5)$ $M_\odot$ interior to $36(D/5)$ kpc. The implied M/L_V ratio is $\approx 16(5/D)$. From analyses of the velocities of companion galaxies we infer that there is mass in the NGC 5128 halo (or in the NGC 5128 Group of galaxies) at or beyond the radius of the most distant star clusters that have so far been identified. Finally, we have used the cumulative cluster luminosity function (normalized to a total cluster system numbering ≈ 600 members, as deduced from new star counts) to argue that the distance to NGC 5128 is ≈ 3 Mpc, rather than the larger values frequently cited. Adoption of such a distance has ramifications for models of NGC 5128 and its energy flux throughout the radio–to–γ-ray realms that lie beyond the scope of this paper.

Our work has only begun to tap the wealth of new information that observations of the oldest components of the peculiar galaxy NGC 5128 have to offer. Were material at higher plate scale or diffraction-limited imagery from spacecraft available, an enormous increase in the number of reliable cluster candidates would almost certainly emerge. As such we offer yet another justification for imagery of NGC 5128 from Space Telescope (or, even better, the proposed, wider field

[16] We are indebted to Gustav Tammann for pointing out to us that the value $B(\max) = 7.75 \pm 0.1$ quoted by Ardeberg and de Groot (1974) results from their attempt to fit two *photographic* prediscovery observations by Austin (1972) to the light curve.

Starlab instrument), as well as under the best possible seeing conditions achievable from the ground. Prior to the availability of diffraction limited imagery from space, multiplex spectroscopic and/or photometric techniques capable of separating globulars from stars and galaxies over a wide field deserve careful consideration as a means of eliminating some of the selection effects inherent in our work.

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APPENDIX

THE SIT VELOCITY SYSTEM

Velocity reductions carried out for the Galactic objects observed during the 1981 April and 1982 May SIT runs and reduced as described in § III*a* and Hesser and Harris (1981) yield average velocities that may be compared with determinations by others. In Table 15 we summarize our 1981 observations for: (1) the solar (twilight) absorption-line spectrum taken with the telescope in the zenith; (2) cluster mean velocities derived from observations of a number of giant and subgiant stars in each cluster; and (3) spectra of ROA 40 and ROA 65 in ω Cen observed several times per night to monitor spectrograph + SIT behavior. (Alternate designations for the globular clusters are: NGC 1851 = C0512−400 (Hesser, Bell, Cannon, and Harris 1982), ω Cen = NGC 5129 = C1323−470, NGC 6752 = C1906−600, and NGC 6352 = C1721−484.) In 1982, only spectra in the second and third categories were obtained, and those were fewer than in 1981. In the columns of the table we present: (1) the object; (2) its declination (in whole degrees); (3) the number, N, of times an object was observed or, in the case of clusters, the number of individual stars observed; (4) the mean radial velocity determined from the N data points; (5) the standard deviation of one of those data points, σ_i; (6) the "catalog" velocity for the object, which is generally taken from Webbink (1981) except for the 0 km s^{-1} adopted for the twilight sky and the (lower weight) NGC 6352 value from Shawl, Hesser, and Meyer's (1981) image-tube study; and (7) the difference between the observed and catalog velocities.

Several remarks may be made on the basis of the 1981 data in Table 15. First, the weighted mean difference treating all determinations as being of equal weight is +5.8 km s^{-1}, which is sufficiently small that we feel justified in neglecting it. (It would be −0.7 km s^{-1} if the NGC 1851 observations, which were generally secured at very large hour angles, were deleted.) Second, there is no convincing evidence for a

TABLE 15

Summary of SIT Radial Velocity Determinations for Galactic Objects

Object (1)	Decl. (°) (2)	N (3)	$\langle V_{r,\odot}\rangle$ (km s^{-1}) (4)	σ_i (km s^{-1}) (5)	$V_{\rm cat}$ (km s^{-1}) (6)	$\langle V_{r,\odot}\rangle - V_{\rm cat}$ (km s^{-1}) (7)
			1981 Data			
Twilight Sky	−30	17	10	24	0	10
NGC 1851	−40	18	356	38	319	+37
NGC 5139-ROA 65	−47	14	248	18	245	3
NGC 5139-ROA 40	−47	13	240	14	223	17
NGC 5139	−47	20	220	51	228	−8
NGC 6352	−48	10	−128	28	−121	−7
NGC 6752	−60	13	−52	30	−32	−20
			1982 Data			
NGC 5139-ROA 65	−47	7	251	36	245	6
NGC 5139-ROA 40	−47	9	245	21	223	17
NGC 6352	−48	10	−113	13	−121	8

dependence of the derived velocities upon declination. Third, the observations of ω Cen, which is located near to NGC 5128 on the sky, suggest that the zero-point of our velocity system is satisfactory for NGC 5128. Fourth, the higher σ_i values for ω Cen itself reflect the fact that most of the stars observed were faint subgiants in the vicinity of the turnoff and that they were usually observed for only 30 minutes.

For the 1982 run spectra were obtained on parts of three nights (May 19–21 UT), although the NGC 5128 data were secured only on the second (10 candidates) and third (three candidates) nights. The mean velocity difference ($V_{obs} - V_{cat}$) of all suitable comparison stars from the run is 8 km s^{-1}, which again is sufficiently small that we have chosen not to apply it to the velocities in Table 1. However, the errors are larger for the 1982 observations of ROA 40 and ROA 65. This appears to be due to a zero-point shift, in the sense that the mean zero-point difference based on ω Cen observations alone for the second night (the one on which most NGC 5128 candidates, including clusters 22 and 23, were observed) seems to be larger than for the third night. Due to weather problems and small number statistics, we do not feel that we have enough data to convincingly map this behavior, and we ignore it. Therefore, it is possible that the velocities listed in Table 1 for clusters 22 and 23 should be decreased by ≈ 30 km s^{-1}.

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