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BLUE AND VISUAL CONCENTRIC APERTURE PHOTOMETRY OF THE GLOBULAR CLUSTERS

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ABSTRACT

Visual and blue photoelectric measurements obtained at Cerro Tololo Inter-American Observatory of 101 globular clusters in the Galaxy and one in the Large Magellanic Cloud are presented. This extensive multiaperture photometry has been analyzed with all other available $(B-V)$ color-index data to address the question of color gradients in globular clusters. The data suggest that the colors of 19 clusters appear to be redder when measured through smaller apertures and the colors of ten clusters appear to be bluer through smaller apertures. No conclusions can be drawn for a number of other clusters due to the large scatter in measurements made by various observers. Color gradients, however, appear to be consistent with the random presence of one or a few relative bright stars whose color may differ appreciably from the average of other stars in the cluster; the data thus give no evidence for radial variations of the stellar population within the clusters. This agrees with similar conclusions drawn by Kron (1966), Hanes and Brodie (1985), and others.

Key words: globular clusters–photometry

I. Introduction

From the study of concentric aperture photometry, there has been only little evidence presented to support the existence of radial color gradients in globular clusters. As early as 1936, Stebbins and Whitford noted in their pioneering photoelectric work, ". . . tests . . . failed to indicate measurable differences in color at different apparent distances from the center [of clusters]." The same results were noted by Kron and Mayall (1960) and later by Kron and Guetter (1976) in extensive multiaperture photoelectric measurements in the *PVI* and six-color photometric systems, respectively. On the other hand, Stebbins (1950) stated that six-color photometry showed "as much as 0.17 mag difference in the $(V-I)$ scale, inner redder than the outer region," could be found in some clusters. Dufay and Bigay (1959) also indicated that "certain amas sont plus rouges ver le centre," but published no data to back up this assertion. More recently Chun and Freeman (1979) found that eight clusters of the 24 they observed were "significantly redder" toward their centers.

Of more importance is the significance or interpretation of color gradients if they exist. Oort and van Herk (1959) and Woolf (1964) suggested that mass loss and subsequent segregation of the red giants and horizontal-branch stars of different mass would occur in clusters and would thus produce radial color variations; however, as dynamical relaxation times are generally longer than horizontal-branch lifetimes and mass differences are small, it is difficult to see that this mechanism is realistic (Freeman 1978). Alternatively, an observed color gradient might reflect an initial radial inhomogeneity in the chemical composition of the material out of which the cluster stars formed (Freeman 1978; Chun and Freeman 1979).

On the other hand, radial color gradients might be artifacts of the observational situation. Clusters tend to be found close to the plane of the Galaxy where the background star density is great; determination of the proper sky correction to apply to the photometric measurements of the cluster plus sky is thus sometimes difficult, particularly in regions where the interstellar absorption across the cluster field is not uniform. While this problem can be minimized by preselection of sky areas or by multiple sky measurements around each cluster, it is likely that discrepancies between series of multiple-aperture data on the same cluster by different observers can be attributed in part to the matter of the background correction. Second, the distribution of stars in a cluster is a statistical distribution. The random inclusion in an aperture of one or a few bright stars whose color may differ slightly from the mean of the cluster stars can produce a spurious appearance of a color gradient. King (1966) pointed out that the statistical effects of the distribution of stars will dominate observational errors, a point which has been

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reiterated by Da Costa (1979), Buonanno *et al.* (1981), Hanes and Brodie (1985), and others; Da Costa noted in particular that the problem becomes even more severe for clusters with large core radii (especially when the observing aperture is smaller than the core radius) and for relatively nearby clusters where the bright red giants are more clearly resolved than for more distant clusters. Related to this second point is the typical manner in which clusters have been observed. Clusters are extended objects; at the telescope it is sometimes difficult to determine the true cluster center, especially for the smallest apertures which may be employed. There is a tendency to preferentially set on a single star or a random clump of bright stars when the cluster center is not otherwise well defined by the overall brightness gradient of the unresolved stars; a spurious color gradient thus can be produced. A similar result will be produced if centering is accomplished by maximization of the photometer output.

In order to study the existence of color gradients in clusters we have combined our $(B-V)$ photometry with all other available photometry. Although in a number of cases there are distressingly large discrepancies between the series of measurements by different observers, it is apparent that color gradients are present in many clusters; while the photometry of a number of clusters suggests they are redder in their central regions, cases in which the central regions appear to be bluer also exist. The data are consistent with the interpretation (Kron 1966; Hanes and Brodie 1985) that color gradients are not evidence for radial variation of the stellar population within clusters, but rather are produced by the random distribution across the cluster of the few brightest stars whose colors may vary from the cluster mean.

II. Observations

In 1976 we began a program of observations at Cerro Tololo Inter-American Observatory of as many of the globular clusters of our Galaxy as possible. The primary goal was to obtain accurate luminosity growth curves to assess the validity of dynamical models which have been computed to reproduce the structures of clusters (cf. King 1966) and to determine cluster structural parameters (cf. Peterson and King 1976); this aspect of the study will be addressed in a later paper in this series. A second goal was to study the question of the existence or nonexistence of color gradients within clusters. The multiaperture photometric observations were obtained during 28 complete or partial nights during the years 1976 to 1980. Approximately 4000 V and B measurements were made with the 0.4-, 0.9-, 1.0-, and 1.5-meter telescopes with the use of various series of aperture sizes and an S-20 photometer with standard V and B filters. The data for each aperture size are presented in Tables I through VII; where multiple observations were obtained on the same or on different nights, an average is given with the error of the mean in parentheses (in units of 0.01 magnitude). Of the clusters in the Milky Way Galaxy, 101 were observed as well as NGC 1841 which is generally considered to be a member of the Large Magellanic Cloud system.

III. The Existence of Color Gradients

$(B-V)$ color indices obtained in this study and compiled from all published sources are plotted as a function of logarithmic radius for part of the total sample of clusters in Figures 1 through 3. The data for clusters in which the measurements through the smaller apertures appear redder than measurements made with apertures that contain a larger fraction of the light coming from the clusters are plotted in Figure 1. In Figure 2 the opposite is shown; i.e., clusters in which the central regions appear bluer than the light coming from the cluster as a whole. Finally, the data for two clusters in which the trend of color with aperture radius appears more complicated are shown in Figure 3. The sources of data are listed at the bottom of each graph; the author code is given in Table VIII. The core radius for each cluster (Webbink 1984) also is indicated on each graph.

Apparent changes in the observed $(B-V)$ color indices as the size of the observing aperture is increased are present in 29 clusters (Table IX). Of these, in 19 clusters it is found that the observed color of the central region is redder than the mean color found for large aperture sizes. In a smaller number of cases (ten) a bluer central region appears to be present.

The question of the existence of color gradients cannot be addressed at this time for a number of clusters due to large scatter in the data obtained by different observers or due to a paucity of data. For those clusters with an adequate number of data, selection for inclusion in the list of Table IX has been made in an extremely conservative manner. A preliminary selection of candidates was chosen on the basis of least-squares fits of the form

$$(B-V)(r) = (B-V)_0 + \alpha \log (r) \quad .$$

Clusters for which σ_α, the standard error of α, is larger than the value of α were immediately rejected as were clusters for which the value of α could be significantly changed by the elimination of extraneous $(B-V)$ color-index measurements (defined as those for which $(B-V)_{\text{observed}} - \langle (B-V)(r)_{\text{other observers}} \rangle > 2\sigma_\alpha$). In a few instances the data of a specific observer were not used when such data clearly are discordant when compared to the trend shown by the data of all other observers. A number of clusters (NGC 5272, NGC 6205, NGC 6342, NGC 6380, NGC 6401, NGC 6642, and IC 4499) were also not included because a change of color with radius was apparent only in the data of one observer and could not be confirmed by other available independent measurements. Finally, a few additional clusters (e.g.,

TABLE I

V Magnitude Measurements with the CTIO 0.4-m Telescope

Cluster NGC	Aperture diameters (arc min) 0.238	0.419	0.631	0.840	1.116	1.518	2.100	2.809	5.487	N*
104	9.20(0)	7.88(0)	7.05(2)	6.61(5)	6.24(2)	5.89(1)				2,3
288		13.20(20)	12.09(14)	11.49(8)	11.08(6)	10.63(2)	10.10(1)	9.62(2)	8.61(4)	1,3
362	9.72(10)	8.65(1)	8.04(0)	7.71(1)	7.50(1)	7.27(1)	7.06(2)	6.89(1)	6.62(1)	2,3
1261	12.56	10.99	10.23	9.84	9.49(2)	9.13(4)	8.84(1)	8.64(3)	8.39(1)	1,3
2298	13.35	12.00	11.29	10.79						1
2808	9.84	8.70	8.04	7.66	7.45(4)	7.10(3)	6.82(3)	6.62(3)		1,2
3201			11.08	10.47	10.10(13)	9.38(1)	8.80(4)	8.41(9)		1,2
4147	12.98(13)	11.93(2)	11.43(2)	11.19(2)	11.08(2)	10.82(2)	10.61(2)	10.49(1)		3,3
4372			12.41	12.08(11)	11.77(12)	11.09(5)	10.29(4)	9.74(6)		1,4
4590	13.32(4)	11.91(6)	11.04(5)	10.42(3)	10.29(8)	9.74(4)	9.33(5)	8.99(3)		3,4
4833	13.00(16)	11.64(6)	10.67(3)	10.12(1)	9.68(5)	9.12(1)	8.65(4)	8.26(1)		3,4
5024	12.15(23)	10.83(12)	10.01(15)	9.55(8)	9.28(2)	8.90(2)	8.54(1)	8.29(1)		2,2
5139	11.65(11)	10.24(8)	9.22(8)	8.53(4)						2
5286	10.82(7)	9.57(2)	8.94(1)	8.59(1)	8.39(1)	8.05(0)	7.80(1)	7.62(2)		3,2
5634	12.52(12)	11.32(4)	10.84(8)	10.52(8)	10.33(8)	10.04(3)	9.81(1)	9.61(1)		3,4
5694	11.94(2)	11.24(1)	10.88(1)	10.69(1)	10.70(10)	10.52(6)	10.36(2)	10.24(1)		3,4
IC 4499					12.35(1)	11.34(3)	10.98(1)	10.71(6)		2
5824	10.63(3)	9.99(1)	9.69(0)	9.51(1)	9.48(7)	9.37(4)	9.21(3)	9.12(1)		3,3
5897	15.26(2)	13.57(1)	12.77	11.91	11.65(13)	11.15(12)	10.63(6)	10.09(7)	9.03	1,4
5904	10.60(5)	9.41(1)	8.68(1)	8.21(2)	7.85(1)	7.48(0)	7.10(2)	6.83(1)		2,2
5927	12.82(8)	11.45(7)	10.64(2)	10.10(1)	9.75(1)	9.31(1)	8.93(1)	8.61(1)		3,3
5946	12.47(12)	11.58(3)	10.98(2)	10.69(1)	10.32(3)	10.24(4)	10.01(3)	10.04(5)		2,3
5986	12.21(12)	10.85(7)	9.96(7)	9.42(6)	9.48(11)	8.90(1)	8.44(1)	8.06		2,2
6093	10.13(4)	9.20(2)	8.70(2)	8.44(2)	8.29(2)	8.08(2)	7.88(2)	7.69(0)		2,3
6101	14.18(27)	13.13(18)	12.15(3)	11.76(3)	11.63(14)	11.12(9)	10.51(3)	9.99(2)		1,3
6121	12.57(28)	11.19(12)	10.13(2)	9.47(6)	9.22(5)	8.71(4)	8.11(2)	7.65(1)		2,3
6139	12.00(1)	11.07(0)	10.57(1)	10.29(2)	10.16(6)	9.90(3)	9.69(5)	9.46(4)		2,3
6144	14.29(28)	13.23(13)	12.51	11.98(19)						2
6171	13.06(12)	11.93(1)	11.04(9)	10.63(5)	10.39(6)	9.98(3)	9.54(2)	9.24(1)		2,2
6218	12.76	11.47	10.36	9.89	9.66(8)	9.16(3)	8.65(5)	8.18(3)	7.36	1,2
6235	13.61(19)	12.21(2)	11.74(2)	11.32(3)	11.16(1)	10.84(3)	10.46(2)	10.20(2)		4,4
6254					9.09(7)	8.49(3)	8.06(3)	7.69(2)	7.09	3
6266	10.17	9.17	8.54	8.09	7.92(1)	7.59(1)	7.31(2)	7.11(0)		1,2
6273	11.34	10.03	9.30	8.83	8.57(7)	8.15(2)	7.71(2)	7.45(6)		1,3
6284	11.91(13)	10.97(3)	10.42(3)	10.09(2)	9.93(6)	9.73(3)	9.45(5)	9.29(2)		2,2
6287	13.30(3)	11.98	11.33	10.85	10.67(8)	10.26(3)	9.98(1)	9.78(2)		1,2
6293	11.46(7)	10.40(1)	9.92(2)	9.65(4)	9.41(2)	9.12(2)	8.92(1)	8.77(8)		1,2
6304	12.05(2)	10.87(10)	10.16(1)	9.77(3)	9.62(2)	9.31(1)	9.08(4)	8.81(1)		2,3
6316	12.06(1)	11.09(0)	10.56(1)	10.27(1)	10.21(4)	9.92(7)	9.73	9.20(7)		2,2
6325	13.20	12.76(0)	12.19(4)	11.89(1)	11.75(4)	11.44(2)	11.16(6)	10.97(2)		1,3
6333	11.80	10.47	9.82	9.41	9.16(5)	8.72(1)	8.37(2)	8.16(1)		1,2
6342	12.88(3)	11.92	11.39	11.08	10.84(0)	10.63(5)	10.42(4)	10.03(4)		1,2
6352	13.36(0)	11.93	11.14	10.65	10.44(13)	9.97(9)	9.46(4)	9.08(4)		1,4
6355		12.29(4)	11.57(1)	11.30(10)	11.01(2)	10.72(3)	10.48(1)	10.17(14)		1,3
6356	11.67	10.63	9.96	9.62	9.35(2)	9.06(2)	8.81(2)	8.63(1)		1,2
6362	14.02(37)	12.38(24)	11.42(1)	10.82(3)	10.26(4)	9.71(3)	9.18(6)	8.78(3)		1,3
6366				12.88(7)	12.42(6)	11.82(8)	11.18(7)	10.67(5)		1,2
6388	9.51	8.55	8.05	7.78	7.64(2)	7.41(1)	7.23(2)	7.04(2)		1,2
6397	11.40	10.11	9.42	9.02	8.66(5)	8.09(8)	7.49(5)	7.14(1)	6.56	1,2
6402	13.12	11.78	10.95	10.37	9.84(6)	9.31(3)	8.81(2)	8.43(2)	7.85	1,3
6426				12.57(2)	12.42(5)	12.06(6)	11.52(10)	11.42(1)		1,3
6440	12.01	11.12	10.65	10.41	10.22(1)	10.03(2)	9.81(2)	9.71(1)		1,2
6441	10.05	9.06	8.54	8.29	8.12(1)	7.92(1)	7.73(1)	7.55(3)		1,3
6453	12.48	11.60	11.05	10.66						1
6496		13.04	12.31	11.77	11.18(5)	10.71(4)	9.84(14)	9.52(2)		1,2
6517	13.05(2)	12.34	11.81	11.51	11.38(1)	11.17(3)	10.94(3)	10.78(5)		1,2
6522	11.39	10.46	9.97	9.59	9.37(3)	9.14(3)	8.90(7)	8.65(10)		1,3
6528	12.13	11.14	10.72	10.51	10.31(7)	10.18(7)	9.89(14)	9.84(23)		1,4
6535			12.40	12.03	11.81	11.24	10.97	10.72		1,1
6539			12.61	12.17	11.80	11.38	10.94(2)	10.48(3)		1,2

*Number of measurements, respectively, through the 4 smallest and the 5 largest apertures.

TABLE I (Continued)

Cluster NGC	0.238	0.419	0.631	Aperture diameters (arc min) 0.840	1.116	1.518	2.100	2.809	5.487	N
6541	10.27	9.22	8.58	8.21	8.03(0)	7.74(2)	7.46(1)	7.26(2)		1,2
6544	12.90	11.31	10.73	10.26	9.75(3)	9.49(3)	9.16(4)	8.86(4)		1,3
6553	12.95	11.58	10.68	10.13	10.00(4)	9.53(5)	8.98(3)	8.67(1)		1,3
6558	12.60(11)	11.60(3)	11.15(1)	10.83(0)	10.64	10.33	10.08	9.92		2,1
6569	12.63(8)	11.43(5)	10.63(1)	10.24(2)	10.02(1)	9.71(2)	9.49(6)	9.23(0)		2,3
6584	13.21	11.63	10.75	10.41	10.08(2)	9.77(2)	9.43(2)	9.14(1)		1,3
6624	10.83(4)	9.96(0)	9.48(2)	9.20(2)	9.04(0)	8.80(2)	8.59(2)	8.46(3)		2,2
6626	10.73	9.58	8.97	8.59	8.42(1)	8.08(1)	7.77(1)	7.56(0)		1,2
6637	11.41(1)	10.27(11)	9.49(3)	9.07(8)	8.86(3)	8.52(2)	8.23(2)	8.05(2)		2,3
6638	11.83(4)	10.76(7)	10.14(0)	9.88(2)	9.70(1)	9.50(1)	9.30(3)	9.17(5)		2,3
6642	11.83(2)	11.14(3)	10.65(2)	10.30(1)	10.18(3)	9.95(4)	9.78(5)	9.64(4)		2,3
6652	11.34	10.56	10.07	9.84	9.61(1)	9.37(1)	9.19(2)	9.09(2)		1,3
6656	12.41	10.52	9.57	9.09	8.36(1)	7.84(1)	7.25(2)	6.72(0)		1,2
6681	10.97(10)	10.20(10)	9.69(11)	9.34(9)	9.06(1)	8.84(0)	8.60(1)	8.36(1)		2,2
6712	13.00(38)	11.62(6)	10.86(3)	10.35(4)	9.97(2)	9.48(5)	9.10(4)	8.76(3)		2,2
6715	9.94	9.09	8.68	8.44	8.31(0)	8.13(1)	7.96(1)	7.85(1)		1,2
6717	11.73	11.18	10.46	10.27	10.19(2)	9.98(2)	9.65(4)	9.03(9)		1,3
6723	12.58	11.03	10.07	9.64	9.22(2)	8.73(2)	8.31(0)	7.97(1)	7.38	1,2
6752	9.95	9.00	8.36	8.02	7.68(2)	7.33(3)	6.92(1)	6.63(2)	6.07(0)	1,3
6760	13.83(7)	12.36(3)	11.80(5)	11.22(14)	10.60(4)	10.24(2)	9.89(3)	9.65(3)		1,3
6809	14.06	12.50	11.44	10.65	10.07(8)	9.52(1)	8.61(8)	8.04(2)	7.06	1,2
6838		11.94	10.91	10.32	10.13(1)	9.63(6)	9.14(2)	8.80(1)	8.01	1,2
6864	10.66(4)	9.89(1)	9.48(2)	9.25(1)	9.11(1)	8.92(1)	8.79(1)	8.67(1)		3,3
6934	12.06(21)	10.81(2)	10.12(2)	9.84(4)	9.63(1)	9.40(1)	9.18(0)	9.01(1)		2,2
6981	13.11(19)	12.16(16)	11.30(2)	10.81(4)	10.57(8)	10.21(3)	9.83(8)	9.62(2)		3,2
7006	13.42(27)	12.06(7)	11.54(3)	11.28(5)	11.09(3)	10.92(6)	10.81(5)	10.72(4)		3,2
7078	9.65(1)	8.78(6)	8.14(1)	7.93(7)	7.61(1)	7.34(1)	7.10(1)	6.91(1)	6.61(1)	2,3
7089	10.57(12)	9.29(8)	8.50(5)	8.15(6)	7.83(4)	7.46(2)	7.14(2)	6.94(1)	6.63(2)	2,3
7099	10.82(3)	9.90(1)	9.35(1)	9.04(0)	8.80(3)	8.48(1)	8.20(1)	7.99(1)	7.68(1)	2,2

NGC 6316 and NGC 6522) were eliminated when closer inspection of the radial run of $(B-V)$ data showed a constancy in color except for a few measures through the largest radii which could be attributed to inclusion within those apertures of a single relatively bright star. The clusters of Table IX, therefore, should represent the best candidates for which the currently available concentric-aperture photometry suggests the existence of radial variations in the $(B-V)$ color index.

Table IX does not include several clusters for which other investigators have color gradients. Of the eight clusters with redder centers suggested by Chun and Freeman (1979), Table IX does not include NGC 104, NGC 5139, NGC 5272, or NGC 7006. From spot measures, Chun and Freeman concluded that the exterior of NGC 104 ($r > 2'$) is bluer by about 0.1 mag. This is not in conflict with concentric aperture data as, for large apertures, the redder central light dilutes the bluer light contribution significantly to make an apparent color change with radius rather difficult to detect. Buonanno *et al.* (1981), however, have disputed the reality of the conclusion made from spot measurements. It should be noted, too, that intercomparison of data for this cluster shows large disagreements between various observers; overall we find $(B-V) = (0.880 \pm 0.008) - (0.018 \pm 0.017) \log r$ with an rms error of the fit of 0.049 mag. Smith (1979) has reported a radial spectroscopic variation which can be explained by mass segregation and crowding of the stars as well as a radial abundance gradient. For NGC 5139, we obtain $(B-V) = (0.799 \pm 0.005) - (0.005 \pm 0.014) \log r$, $\sigma_{\rm fit} = 0.031$ mag.; thus, the observation by Oort and van Herk (1959) that the red giants are more concentrated than the horizontal-branch stars does not seem apparent in the $(B-V)$ data. For NGC 5272, $(B-V) = (0.688 \pm 0.006) - (0.009 \pm 0.014)$, $\sigma_{\rm fit} = 0.028$; Oort and van Herk also found the red giants in this cluster to be more concentrated to the center than the horizontal-branch stars. And for NGC 7006, $(B-V) = (0.753 \pm 0.012) + (0.025 \pm 0.027)$, $\sigma_{\rm fit} = 0.050$. From surface photometry, Harvel and Martins (1977) found the core of NGC 6624 to be substantially bluer, but their data are in disagreement with concentric aperture measurements. Similarly, the redder core for NGC 6640 (Martins, Harrel, and Miller 1980) is not substantiated by concentric-aperture photometry.

To understand the nature and origin of these apparent gradients, star-count studies and color-magnitude diagram studies were surveyed as well as the author's origi-

TABLE II

V Magnitude Measurements with the CTIO 0.9-m Telescope

Cluster NGC	Aperture diameters (arc min) 0.289	0.415	0.600	0.836	N
2808	9.39	8.76	8.21	7.74	1
Pal 3			15.84	15.24	1
3201		11.83	11.25	10.62	1
4147	12.46	11.92	11.52	11.16	1
4372				12.29	1
4590	12.57	11.85	11.11	10.50	1
4833		11.88	10.99	10.38	1
5286	10.21	9.59	9.09	8.65	1

Cluster NGC	Aperture diameters (arc min) 0.145	0.255	0.384	0.512	N
5694	12.51	11.71	11.27	11.03	1
IC 4499	16.91	15.45(12)	14.30(2)	13.67(3)	2
5824	11.25(5)	10.39(2)	10.02(1)	9.80(1)	3
5897	16.57(63)	15.13(32)	13.50(61)	12.99(57)	2
5927	14.03	12.54	11.45(3)	10.91(8)	2
5946	13.34(10)	12.21(2)	11.64(3)	11.22(4)	3
5986	13.26	11.81	10.91	10.34	1
6093	10.93(7)	10.02(18)	9.48(24)	9.04(12)	2
6101	15.52(26)	14.34(12)	13.64(6)	13.09(5)	3
6121	14.24	12.79	11.27	10.65	1
6139	12.87(7)	11.79(8)	11.20(11)	10.82(3)	3
6144	16.45(1)	14.69(52)	13.89(55)	13.19(29)	2
6171	14.13	13.09	12.00(8)	11.42(5)	2
6235		13.44	12.55(24)	11.97(3)	3
6284	12.88(24)	11.64(12)	11.08(4)	10.72(5)	4
6287	14.03(19)	12.94(6)	12.17(8)	11.70(8)	2
6293	12.45(16)	11.15(4)	10.51(5)	10.20(7)	3
6304	13.46	11.99	11.04(3)	10.54(10)	2
6316	13.19	11.88(5)	11.34(8)	10.94(17)	2
6325	14.34	13.48	12.82		1
6333			10.65	10.10	1
6342	13.77	12.70	12.09(11)	11.82(13)	2
6352			12.12(19)	11.55(30)	1
6355	14.59	13.22	12.33(9)	11.90(10)	2
6356	12.91	11.64	10.67(0)	10.25(7)	2
6380				13.03(1)	1
6388	10.39(17)	9.31(3)	8.64(0)	8.27(1)	2
6397			10.17	9.67	1
6440	13.15	12.11	11.48	10.97	1
6441	11.07	9.79(8)	9.23(10)	8.77(1)	2
6453			11.60	11.13	1
6496	16.25	14.83	13.71	13.00	1
6517	13.78	12.76	12.30	11.97	1
6522	11.96(3)	11.10(4)	10.56(3)	10.22(1)	2
6528	13.07	11.76(2)	11.23(8)	10.97(12)	2
6535	14.61	13.73	12.90	12.54(5)	2
6539	16.01	14.33	13.41	12.88	1
6544			11.25	10.55	1
6553		12.06(3)	11.57(3)	10.91(1)	1
6558	13.31(20)	12.31(1)	11.66(4)	11.32(4)	3
6569	13.77	12.39(8)	11.65(11)	11.01(1)	2
6584	13.14	12.04(5)	11.44(7)	11.01(3)	2
6624	11.52	10.47(2)	10.02(3)	9.66(1)	2
6626	11.49	10.51	9.68	9.23	1
6637	12.31	10.98(26)	10.37(20)	9.87(11)	2
6638			10.79	10.33	1
6642	12.44	11.65	11.15(1)	10.84(2)	2
6652	12.05(17)	11.15(7)	10.82(14)	10.47(16)	3
Pal 8	15.42(11)	13.99(5)	13.33(1)	12.70(7)	2
6681	11.63(13)	10.77(11)	10.22(3)	9.91(3)	3
6712	13.99	12.35	11.67	11.13(5)	2

TABLE II (Continued)

Cluster NGC	Aperture diameters (arc min) 0.145	0.255	0.384	0.512	N
6715	10.80(5)	9.80(6)	9.23(4)	8.90(1)	3
6717	12.69(20)	11.65(3)	11.39(7)	10.91(3)	3
6723	13.43(2)	12.14(4)	11.15(1)	10.46(2)	2
6749			14.46	13.77	1
6752	11.01	9.92	9.23	8.78	1
6760	14.64(31)	13.20(5)	12.36(2)	11.72(9)	4
6809	15.14	13.75	12.62	11.95	1
Pal 11			14.18	13.73	1
6864	11.65	10.49(2)	10.04(2)	9.79(4)	2
6934	13.64	11.76	10.90(12)	10.42(11)	2
6981	15.05	13.80	12.69	11.89(19)	2
7006			12.17	11.80	1
7078	11.37	9.83	8.98	8.61	1
7089	11.78	10.51	9.65	9.07	1

TABLE III

V Magnitude Measurements with the CTIO 1.0-m Telescope

Cluster NGC	Aperture diameters (arc min) 0.234	0.323	0.456	0.792	N
288	14.26	13.77	12.93	11.47	1
1261	12.02	11.41	10.90	9.89	1
1851	9.66	9.17	8.86	8.23	1
1904	10.96	10.40	9.28		1
7099	10.50	10.08	9.80	9.02	1
Pal 12		16.55	15.44	14.12	1
7492	16.59	15.97	15.06(25)	14.00(19)	2

nal observing notes. In a few cases, there have been surveys to search for variations in the radial distribution of red and blue stars. This additional information is summarized in the notes for individual clusters which is appended to Table IX.

If these variations are indeed due only to the randomness of the distribution of the few relatively brightness stars in the clusters, then we would further expect that color variations would tend to occur preferentially for those clusters with large core radii which would make concentric aperture observations more subject to chance centering on a particular bright star as well as more influenced by the random distribution of the brightest stars in the clusters (Da Costa 1979). The distribution of core radii taken from the recent tabulation of Webbink (1984) is shown in Figure 4 where it can be seen that the distribution of core radii for the clusters of Table X is essentially the same as the distribution of core radii for all clusters which have been included in this study. Thus while the suggestion of Da Costa may well explain a color trend in data of an individual observer, it may not explain general trends seen in the data of more than one independent investigator. This too may suggest that the statistical distribution of individual stars within the clusters is not the dominant factor; at least part of the variation in appar-

TABLE IV

V Magnitude Measurements with the CTIO 1.5-m Telescope

Cluster NGC	0.124	0.171	0.241	0.415	0.562	0.777	1.040	N*
	Aperture diameters (arc min)							
1841				14.22	13.70	13.09	12.53	1
6316	13.36	12.68	12.17	11.19(4)	10.79(3)	10.41(2)	10.14(1)	1,2
6325				12.93(5)	12.40(1)	12.05(1)	11.75(1)	2
6342	13.64	13.24	12.80	11.88(1)	11.56(0)	11.25(0)	10.90(0)	1,2
6380				13.55(6)	13.09(4)	12.63(17)	12.03(5)	2
6401	14.48	14.04	13.55	12.18	11.85	11.46	10.84	1,1
Pal 6							13.25	1
6453				11.46(6)	11.14(8)	10.65(1)	10.38(7)	2
6517				12.29	11.98	11.64	11.40	1
6522	12.15	11.81	11.43	10.48	10.10	9.72	9.44	1,1
6528	13.57	12.87	12.26	11.18	10.84	10.53	10.32	1,1
6535				12.98	12.62	12.30	11.80	1
6544				11.08	10.60	10.20	9.82	1
6558	13.33	12.93	12.55	11.65	11.30	11.02	10.63	1,1
6569	14.22	13.26	12.62	11.48(3)	10.95(2)	10.43(1)	10.02(2)	1,2
6584				11.45	10.98	10.51	10.15	1
6642	12.99	12.39	11.92	11.15	10.85	10.42	10.17	1,1
Pal 8			14.51	13.27(8)	12.63(7)	11.92(3)	11.45(6)	1,2

* Number of nights, respectively, for measurements with the 4 smallest or 4 largest apertures.

TABLE V

B-V Measurements with the CTIO 0.4-m Telescope

Cluster NGC	0.238	0.419	0.631	0.840	1.116	1.518	2.100	2.809	5.487
	Aperture diameters (arc min)								
104	0.88((1)	0.88(1)	0.90(1)	0.89(1)	0.90(1)	0.89(0)			
288		0.48(8)	0.64(4)	0.65(3)	0.69(2)	0.66(1)	0.64(2)	0.62(3)	0.69(2)
362	0.86(4)	0.78(2)	0.79(1)	0.79(1)	0.80(1)	0.78(1)	0.77(0)	0.77(0)	0.77(1)
1261	1.01	0.73	0.67	0.66	0.71(1)	0.70(0)	0.71(1)	0.73(1)	0.72
2298	0.81	0.82	0.71	0.81					
2808	0.99(2)	0.94(1)	0.93(1)	0.92(1)	0.90(0)	0.91(1)	0.91(1)	0.90(1)	
3201	0.83(16)	0.90(16)	1.00(1)	0.99(2)	0.93(4)	0.96(1)	0.97(1)	0.99(2)	
4147	0.70(5)	0.59(3)	0.58(2)	0.59(1)	0.56(1)	0.60(1)	0.61(1)	0.62(2)	
4372			1.10	1.03(5)	0.98(1)	0.97(3)	0.98(2)	1.03(3)	
4590	0.61(3)	0.65(4)	0.59(2)	0.60(3)	0.61(1)	0.62(1)	0.60(1)	0.61(1)	
4833	0.81(8)	0.78(6)	0.84(2)	0.92(2)	0.98(3)	0.97(2)	0.96(2)	0.95(1)	
5024	0.67(1)	0.70(2)	0.68(3)	0.74(7)	0.66(1)	0.65(1)	0.64(0)	0.65(0)	
5139	0.78(6)	0.75(4)	0.78(3)	0.81(1)					
5286	0.88(1)	0.91(1)	0.89(0)	0.89(0)	0.90(1)	0.89(1)	0.88(0)	0.88(1)	
5634	0.74(5)	0.72(2)	0.68(1)	0.65(2)	0.67(1)	0.69(2)	0.68(1)	0.70(1)	
5694	0.73(3)	0.71(1)	0.70(1)	0.71(1)	0.74(1)	0.72(1)	0.74(2)	0.73(0)	
IC 4499					0.82(2)	0.93(0)	0.94(2)	0.96(8)	
5824	0.77(1)	0.76(0)	0.76(1)	0.77(2)	0.74(2)	0.76(1)	0.76(1)	0.74(0)	
5897	0.72(4)	0.86(6)	0.68	0.75	0.76(1)	0.76(3)	0.74(3)	0.71(2)	
5904	0.78(4)	0.77(1)	0.70(1)	0.72(1)	0.71(1)	0.71(1)	0.71(0)	0.71(0)	
5927	1.36(8)	1.33(3)	1.33(1)	1.30(4)	1.31(1)	1.30(1)	1.31(1)	1.33(1)	
5946	1.29(2)	1.31(6)	1.30(4)	1.29(2)	1.33(1)	1.33(2)	1.34(3)	1.21(5)	
5986	0.90(4)	0.91(1)	0.87(1)	0.87(1)	0.85(1)	0.86(1)	0.89(1)	0.91	
6093	0.82(1)	0.85(1)	0.84(1)	0.83(1)	0.86(0)	0.86(1)	0.86(0)	0.87(1)	
6101	0.66(16)	0.67(14)	0.81(1)	0.74(1)	0.77(4)	0.72(4)	0.68(2)	0.70(1)	
6121	0.95(9)	0.93(1)	0.95(3)	1.01(2)	1.00(1)	1.02(1)	1.02(1)	1.00(1)	
6139	1.42(2)	1.40(2)	1.40(1)	1.40(1)	1.37(3)	1.42(2)	1.41(1)	1.42(2)	
6144	0.96(12)	1.03(4)	0.90	1.05(1)					
6171	1.30(3)	1.29(7)	1.28(2)	1.27(1)	1.27(1)	1.21(0)	1.19(1)	1.14(0)	
6218	0.82	0.80	0.89	0.82	0.83(2)	0.81(1)	0.81(1)	0.86(1)	0.88
6235	1.13(5)	1.18(1)	1.09(3)	1.07(2)	1.04(2)	1.00(4)	1.06(1)	1.10(2)	
6254					0.91(3)	0.99(4)	0.97(4)	0.93(0)	0.92
6266	1.13	1.15	1.14	1.18	1.19(1)	1.21(1)	1.20(1)	1.21(1)	
6273	1.03	1.11	1.09	1.08	1.06(1)	1.05(1)	1.04(1)	1.04(1)	
6284	0.98(1)	0.98(1)	0.99(1)	1.00(1)	1.01(3)	1.00(1)	1.01(5)	1.00(3)	

TABLE V (Continued)

Cluster	Aperture diameters (arc min)								
NGC	0.238	0.419	0.631	0.840	1.116	1.518	2.100	2.809	5.487
6287	1.19(4)	1.18	1.12	1.20	1.21(4)	1.23(1)	1.18(5)	1.27(1)	
6293	1.01(5)	0.94(2)	0.94(2)	0.96(0)	0.95(2)	0.98(2)	0.96(1)	0.96	
6304	1.32(1)	1.31(3)	1.33(1)	1.34(1)	1.33(1)	1.33(1)	1.32(2)	1.32(2)	
6316	1.39(8)	1.41(4)	1.44(2)	1.43(2)	1.43	1.43(2)	1.38	1.19(0)	
6325	1.47	1.68(1)	1.67(3)	1.65(1)	1.66(4)	1.66(3)	1.69(4)	1.68(7)	
6333	1.09	1.07	1.00	1.00	0.99	1.02(2)	1.01(2)	1.00(2)	
6342	1.29(0)	1.31	1.21	1.26	1.40(3)	1.26(6)	1.29(4)	1.18(1)	
6352	1.06(2)	1.13	1.14	1.12	1.06(1)	1.07(1)	1.07(1)	1.06(1)	
6355	1.23	1.56(1)	1.52(2)	1.44(2)	1.44(2)	1.47(1)	1.46(0)	1.47(1)	
6356	1.16	1.13	1.13	1.13	1.13(2)	1.14(1)	1.14(1)	1.14(1)	
6362	0.78(7)	1.00(18)	1.00(1)	0.94(2)	0.97(1)	0.98(3)	0.90(2)	0.86(1)	
6366				1.54(5)	1.40(4)	1.45(3)	1.42(2)	1.40(2)	
6388	1.19	1.19	1.18	1.17	1.18(0)	1.18(1)	1.17(0)	1.10(1)	
6397	0.50	0.60	0.56	0.58	0.65	0.69(4)	0.75(1)	0.75(1)	0.73
6402	1.21	1.23	1.24	1.24	1.27(0)	1.27(1)	1.27(0)	1.28(1)	1.29
6426				1.06(3)	1.04(1)	1.04(1)	1.05(1)	1.06(1)	
6440	1.98	1.94	1.97	1.96	2.00(1)	1.98(4)	2.02(3)	2.05(1)	
6441	1.25	1.28	1.27	1.27	1.28(0)	1.29(1)	1.27(1)	1.26(2)	
6453	1.38	1.28	1.34	1.46	1.36	1.29	1.24	1.22	
6496		0.93	1.01	1.07	1.02(3)	1.00(3)	0.97(13)	0.90(1)	
6517	1.82(4)	1.75	1.74	1.75	1.78(1)	1.78(0)	1.77(3)	1.76(2)	1.67
6522	1.21	1.21	1.18	1.20	1.24(2)	1.22(1)	1.22(1)	1.18(2)	
6528	1.51	1.56	1.53	1.52	1.56(3)	1.65(5)	1.68(10)	1.66(12)	
6535			0.90	0.78	0.89	0.95	0.96	1.05	
6539			1.64	1.85	1.81	1.83	1.83(2)	1.77(2)	
6541	0.78	0.77	0.75	0.77	0.77(1)	0.77(1)	0.77(1)	0.77(0)	
6544	1.34	1.38	1.36	1.45	1.48(0)	1.46(1)	1.47(1)	1.46(1)	
6553	1.51	1.63	1.69	1.78	1.70(1)	1.67(3)	1.52(0)	1.54(1)	
6558	1.19(6)	1.16(3)	1.11(1)	1.09(1)	1.04	1.06	1.07	1.05	
6569	1.37(3)	1.36(1)	1.35(1)	1.34(0)	1.35(2)	1.37(2)	1.37(1)	1.35(2)	
6584	0.59	0.80	0.82	0.78	0.78(0)	0.77(0)	0.77(0)	0.78(0)	
6624	1.10(2)	1.12(0)	1.13(2)	1.10(1)	1.10(1)	1.11(0)	1.11(0)	1.11(1)	
6626	1.07	1.11	1.09	1.08	1.07(1)	1.08(1)	1.10(0)	1.09(1)	
6637	1.00(3)	1.01(3)	1.01(2)	1.03(0)	1.02(0)	1.03(0)	1.01(0)	1.02(1)	
6638	1.22(2)	1.18(0)	1.20(3)	1.17(1)	1.14(0)	1.15(2)	1.15(0)	1.16(1)	
6642	1.21(9)	1.08(2)	1.10(0)	1.11(0)	1.08(0)	1.08(1)	1.11(1)	1.07(2)	
6652	0.81	0.85	0.89	0.90	0.89(1)	0.90(1)	0.91(1)	0.89(1)	
6656	0.54	1.02	0.94	1.11	0.95(0)	0.96(1)	0.96(0)	1.01(1)	
6681	0.83(1)	0.72(3)	0.71(2)	0.73(1)	0.74(1)	0.72(0)	0.73(1)	0.72(1)	
6712	1.26(2)	1.21(1)	1.16(1)	1.16(1)	1.16(0)	1.12(2)	1.14(1)	1.16(2)	
6715	0.85	0.85	0.86	0.87	0.86(1)	0.86(0)	0.86(1)	0.85(0)	
6717	1.46	1.02	1.04	1.02	1.00(1)	1.00(1)	1.03(2)	1.12(2)	
6723	0.63	0.79	0.77	0.77	0.80(1)	0.78(3)	0.79(1)	0.78(1)	0.77
6752	0.68	0.58	0.61	0.62	0.66(2)	0.68(2)	0.68(0)	0.69(1)	0.71(1)
6760	1.74(3)	1.63(12)	1.61(6)	1.61(10)	1.69(4)	1.69(3)	1.68(2)	1.66(3)	
6809	0.70	0.67	0.64	0.63	0.67(2)	0.65	0.74(3)	0.75(2)	0.75
6838		1.20	1.19	1.25	1.12(7)	1.14(2)	1.06(1)	1.09(4)	1.13
6864	0.93(3)	0.87(1)	0.87(1)	0.87(1)	0.88(0)	0.88(1)	0.89(1)	0.88(1)	
6934	0.91(5)	0.75(0)	0.78(2)	0.75(0)	0.76(1)	0.75(1)	0.77(1)	0.77(3)	
6981	0.75(12)	0.71(8)	0.75(1)	0.78(1)	0.74(1)	0.74(2)	0.78(1)	0.73	
7006	0.65(7)	0.74(3)	0.72(3)	0.73(2)	0.75(1)	0.74(3)	0.72(1)	0.74(0)	
7078	0.67(1)	0.58(7)	0.69(1)	0.60(9)	0.68(1)	0.69(1)	0.70(1)	0.70(1)	0.70(1)
7089	0.59(3)	0.64(2)	0.67(1)	0.66(0)	0.68(1)	0.69(1)	0.70(1)	0.69(1)	0.69(1)
7099	0.48(2)	0.48(2)	0.52(1)	0.53(1)	0.56(2)	0.59(1)	0.62(0)	0.61(1)	0.60

ent color with radius instead may be due to the statistical distribution of foreground stars. On the other hand, if color variations are due to the greater concentration to the center of the more massive and brighter red-giant stars as opposed to the bluer horizontal-branch stars which presumably have lost mass through evolutionary processes,

TABLE VI

B-V Measurements with the CTIO 0.9-m Telescope

Cluster NGC	Aperture diameters (arc min) 0.145	0.255	0.384	0.512
5694	0.68(1)	0.68(0)	0.69(1)	0.70(1)
IC 4499	0.54	0.71(6)	0.81(4)	0.79(2)
5824	0.76(5)	0.79(1)	0.76(1)	0.77(1)
5897	0.45(13)	0.57(1)	0.76(17)	0.75(14)
5927	1.21	1.30	1.26(1)	1.30(2)
5946	1.32(1)	1.32(1)	1.29(3)	1.32(3)
5986	0.90(2)	0.92(2)	0.92(2)	0.94(2)
6093	0.89(5)	0.76(8)	0.75(11)	0.83(1)
6101	0.72(2)	0.66(2)	0.54(2)	0.53(2)
6121	0.77	0.93	0.97	1.00
6139	1.40(2)	1.41(2)	1.37(4)	1.41(1)
6144		0.92(12)	0.93(4)	0.86(2)
6171	1.35	1.29(0)	1.24(5)	1.26(4)
6235	1.04	1.13	0.99(17)	1.05(2)
6284	0.98(19)	0.99(5)	0.97(1)	1.00(3)
6287	1.32(8)	1.25(5)	1.16(2)	1.15(1)
6293	0.95(10)	0.97(2)	0.96(4)	0.99(2)
6304	1.28	1.27	1.26(8)	1.33(0)
6316	1.42	1.44(4)	1.37(0)	1.38(6)
6325	1.81	1.70		1.64
6333			1.00	1.01
6342	1.21	1.25	1.19(1)	1.21(1)
6352			1.05(14)	1.02(22)
6355	1.58	1.58	1.60(5)	1.60(6)
6356	1.09	1.15	1.09(3)	1.18(5)
6380				2.08(1)
6388	1.24(5)	1.20(1)	1.18(1)	1.17(1)
6397			0.60	0.57
6440	1.95	1.84	1.99	1.96
6441	1.27	1.31(2)	1.25(5)	1.28(2)
6453			1.27	1.39
6496	0.91	0.94	0.95	0.95
6517	1.86	1.74	1.73	1.74
6522	1.26(5)	1.25(8)	1.20(2)	1.19(3)
6528	1.54	1.60(5)	1.52(2)	1.50(0)
6535	0.97	1.02	0.96	0.94(5)
6539	1.71	1.82	1.81	1.80
6544			1.44	1.65
6553		1.83(1)	1.58(1)	1.70(1)
6558	1.04(2)	1.08(2)	1.15(1)	1.12(0)
6569	1.31	1.38(10)	1.29(7)	1.36(2)
6584	1.24	1.11(5)	0.87(2)	0.81(2)
6624	1.10	1.15(6)	1.11(1)	1.14(4)
6626	1.13	0.99	1.05	1.07
6637	0.99	1.13(2)	1.03(6)	1.04(2)
6638			1.18	1.20
6642	1.24	1.13	1.07(2)	1.09(4)
6652	0.96(7)	0.91(3)	0.79(4)	0.83(2)
Pal 8	1.33(3)	1.24(0)	1.18(3)	1.16(0)
6681	0.81(7)	0.82(1)	0.72(3)	0.69(2)
6712	1.22	1.30	1.23	1.19(1)
6715	0.94(5)	0.87(1)	0.86(3)	0.88(3)
6717	0.90(11)	1.05(6)	0.92(2)	1.00(3)
6723	0.68(3)	0.64(1)	0.71(1)	0.78(2)
6749			2.26(12)	2.24(12)
6752	0.80	0.70	0.61	0.65
6760	1.77(4)	1.78(4)	1.69(5)	1.77(4)
6809	0.68	0.69	0.60	0.63
Pal 8			1.22	1.31
6864	0.88(1)	0.94(1)	0.88(0)	0.89(1)

TABLE VI (Continued)

Cluster NGC	Aperture diameters (arc min) 0.145	0.255	0.384	0.512
6934	0.84	0.86	0.82(1)	0.84(2)
6981	0.73	0.87	0.71	0.77(4)
7006			0.65	0.68
7078	0.68	0.77	0.74	0.69
7089	0.73	0.63	0.56	0.60

we would expect clusters with redder cores to have shorter central relaxation times. In Figure 4 the distribution of central relaxation times for all clusters of this study with the distribution for the clusters of Table IX is also compared; there is no tendency for clusters with short dynamical relaxation times to have redder cores implying a more centrally concentrated spatial distribution of the more massive stars. In fact, we see the distribution in relaxation time is the same for clusters with bluer central regions as for those with redder central regions; thus, internal dynamical effects can be ruled out as the cause of color gradients. In the few clusters in which the stellar radial distributions have been studied, little correlation seems to exist between the relative central concentration of the red giants compared to the bluer horizontal-branch stars and the observed color gradient. Red giants are more concentrated in NGC 5139 and NGC 5272 (Oort and van Herk 1959), clusters in which no significant color gradient is found, in NGC 5024 (Cuffey 1966) and NGC 6171 (Dickens and Rolland 1972) in which the central color is redder, but also in NGC 7099 (Alcaino and Wamstecker 1982) in which the central color is bluer. Similar radial distributions for the red-giant and the horizontal-branch stars were found in NGC 6397 (Woolley *et al.* 1961), but the cluster appears to have a bluer core. Of these six clusters, the only two with dynamical relaxation times shorter than the stellar evolution-mass loss time scales are rather unexpectedly NGC 7099 ($T_r \sim 3.6 \times 10^6$ years) and NGC 6397 ($T_r \sim 3.0 \times 10^7$ years).

Our conclusion is that the statistical variation in the distribution of the brighter cluster and/or the superimposed field stars must be responsible for color variations; this is further supported by the observations for NGC 6656 and NGC 6752 (Fig. 3) in which one finds a more complicated color trend with radius. In both clusters inspection of direct photographs reveals that the projected radial distributions of the brighter stars are very patchy which may account for the apparently bluer color at intermediate radii.

Finally, this conclusion is supported by detailed cluster simulations based on a realistic cluster luminosity function (Hanes and Brodie 1985). As expected, they found that for small, relatively compact clusters (e.g., NGC 6093), statistical fluctuations in the stellar population and its spatial distribution will tend to have little

TABLE VII

B-V Measurements with the CTIO 1.5-m Telescope

Cluster NGC	0.124	0.171	0.241	0.415	0.562	0.777	1.040
1841				1.08	1.03	0.89	0.86
6316	1.38	1.43	1.38	1.41(1)	1.42(1)	1.43(1)	1.43(1)
6325				1.74(3)	1.70(1)	1.69(0)	1.64(1)
6342	1.14	1.16	1.19	1.27(1)	1.29(0)	1.27(1)	1.33(0)
6380				2.12(2)	2.05(2)	2.00(1)	2.01(1)
6401	1.87	1.70	1.67	1.84(24)	1.55	1.55	1.61
Pal 6							2.84
6453				1.25(7)	1.24(5)	1.34(8)	1.44(2)
6517				1.74(1)	1.74(1)	1.74(0)	1.72(1)
6522	1.23	1.16	1.18	1.21(0)	1.27(0)	1.20(3)	1.22(0)
6528	1.42	1.51	1.52	1.52(1)	1.50(0)	1.48(0)	1.51(0)
6535				0.93(1)	0.93(2)	0.89(1)	0.92(0)
6544				1.49	1.46	1.45	1.45
6558	1.11	1.08	1.10	1.12(2)	1.10	1.08	1.07
6569	1.26	1.39	1.36	1.35(1)	1.34(1)	1.33(0)	1.33(0)
6584				0.89	0.84	0.80	0.78
6642	1.20(2)	1.14(4)	1.11(4)	1.06(3)	1.08	1.10	1.10
Pal 8			1.18	1.20(3)	1.19(4)	1.25(0)	1.23(0)

effect in producing an apparent color gradient. On the other hand, in a large, relatively open cluster such as NGC 5139, statistical fluctuations or the forced presence of a single red-giant star or a single blue horizontal-branch star in the cluster center can cause significant changes in $(B-V)$ (as great as 0.7 mag) over the range of aperture sizes that have been used in actual photoelectric observations.

IV. Integrated $(B-V)$ Color Indices

Although color gradients appear to exist in about 25% of the clusters we have studied, it is still reasonable to determine mean integrated colors. A complete tabulation of $(B-V)$ color indices for 115 globular clusters is given in Table X. Our indices have been determined from averages of the data ($(B-V)$ versus log radius) of all observers except in the cases where color gradients appear to be present; in that situation only data exterior to the region of color change have been used to determine mean color index. Zero-point and scale changes were not considered in relating the observations of various observers to each other except for those observers who had not used the standard *UBV* system (see notes to Table VIII). This manner of color determination alone does not use all possible data, however, for four photometric studies (Kron and Mayall (1960), Rousseau (1964), Koehler (1965) who cites unpublished data of Gascoigne and Menzies, and, in part, Harris and van den Bergh (1974)) do not specifically detail the sizes of the apertures which were used for the photometric measurements. In these cases, the $(B-V)$ values were obtained from both a consideration of color as a function of radius and the additional data, with each observer being given equal weight in the averaging of measurements.

The close agreement of our results with those of Reed (1985) who did consider zero point and scale factors in the transformation of existing data to a "standard" system—arbitrarily chosen to be the *UBV* observations of van den Bergh (1967)—argues that our neglect of transformation equations on an observer-by-observer basis has not introduced any serious systematic error into the final compilations. Further the existence of apparent color gradients in a number of clusters, because these gradients tend to be small or limited to the inner region of the clusters whereas observers have tended to obtain photometry that encompasses the greater portion of the light of the clusters, has apparently had little influence on Reed's determination of the $(B-V)$ color indices. We find that

$$\langle (B-V)_{\rm here} - (B-V)_{\rm Reed} \rangle = 0.000 \pm 0.030 \quad .$$

In Table X we also have listed the $(B-V)$ results compiled by Harris and Racine (1979) in their comprehensive review of cluster data. For a very few cases our $(B-V)$ values may differ appreciably from those given by Harris and Racine primarily due to our use of a significantly larger data base and secondarily due to differences in the manner of averaging and weighting the data from different observers. Overall we have

$$\langle (B-V)_{\rm here} - (B-V)_{\rm Harris\ and\ Racine} \rangle = 0.014 \pm 0.052 \quad .$$

V. Summary

1. The results of concentric aperture photoelectric photometry in globular clusters are presented; data were obtained on 102 clusters.

2. These new $(B-V)$ data have been considered with other available $(B-V)$ data to search for color gradients in clusters: 19 clusters appear to be redder in the center and ten clusters appear to be bluer in the center on the basis of concentric aperture photometric measurements. No gra-

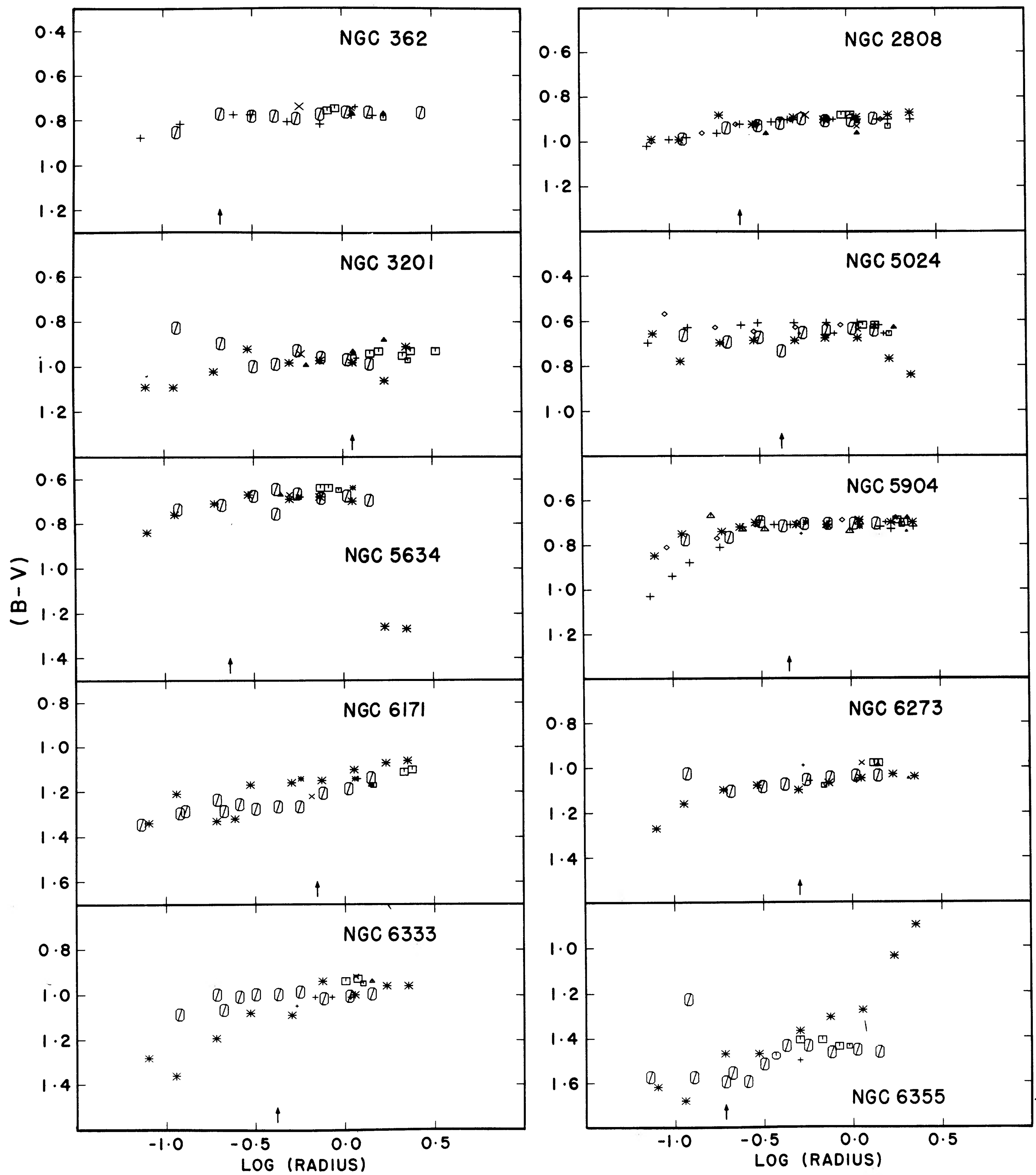

FIG. 1(a)–The run of $(B-V)$ color index with radius of the observing aperture for 19 globular clusters which appear to have redder central regions. The core radius of each cluster (Webbink 1984) is indicated by the vertical arrow. The symbol definition table at the end of this figure (Fig. 1b) indicates the source of data; all references to the literature are listed in Table VIII.

dients could be searched for in a number of other clusters due to sparsity of data or disagreement in color measurements between different observers.

3. The clusters in which gradients appear to exist and the trend of the color gradient do not correlate with differences in central concentration of the red-giant stars

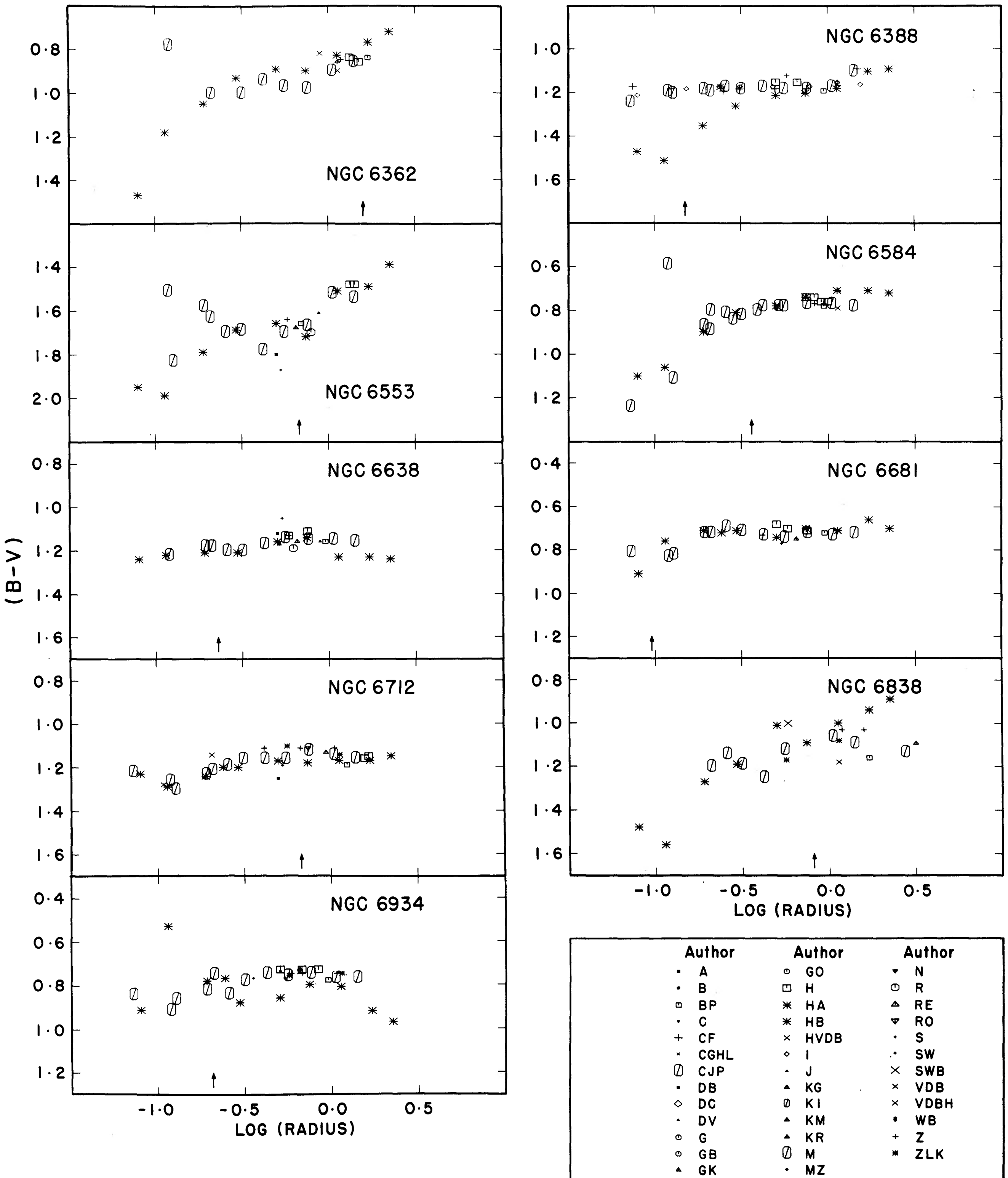

FIG. 1(b)–See caption for Figure 1(a).

relative to the radial distribution of the (bluer) horizontal-branch stars. The relative central concentration of the red giants similarly does not correlate with central relaxation times.

4. Apparent color gradients do not correlate with short dynamical relaxation times in the centers of the clusters. Clusters with both blue and red cores appear to have the same distribution of relaxation times as clusters without

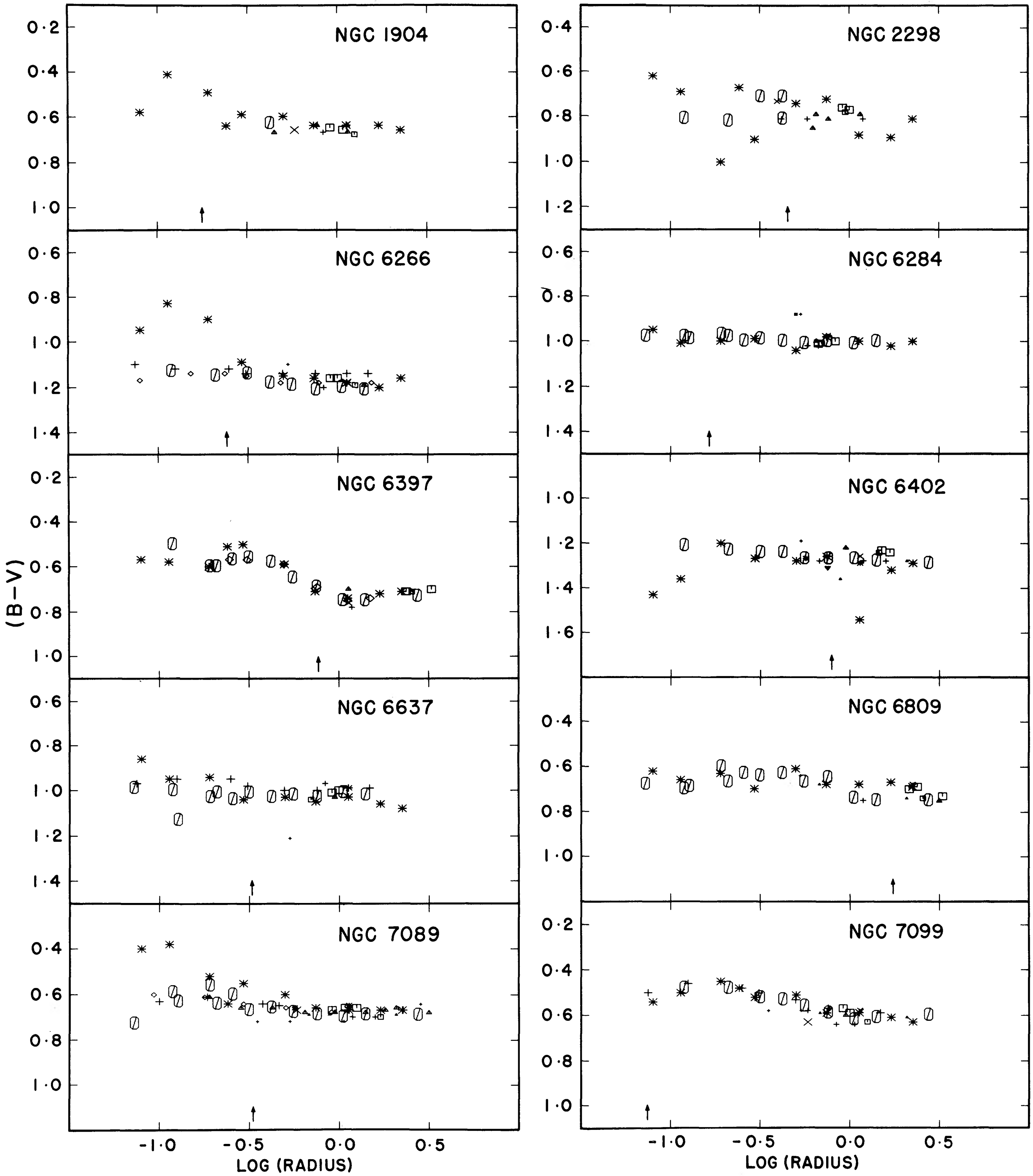

FIG. 2–The run of $(B-V)$ color index with radius for the ten clusters which appear to have bluer central regions. The symbol code is the same as for Figure 1(b).

color gradients.

5. Obvious color gradients do not appear to correlate with reported abundance gradients.

6. In several color-gradient clusters a specific single object can account for the observed color gradient. In other clusters with color gradients, inspection of direct photographs shows a very patchy radial distribution for the brightest stars, presence of crowded foreground

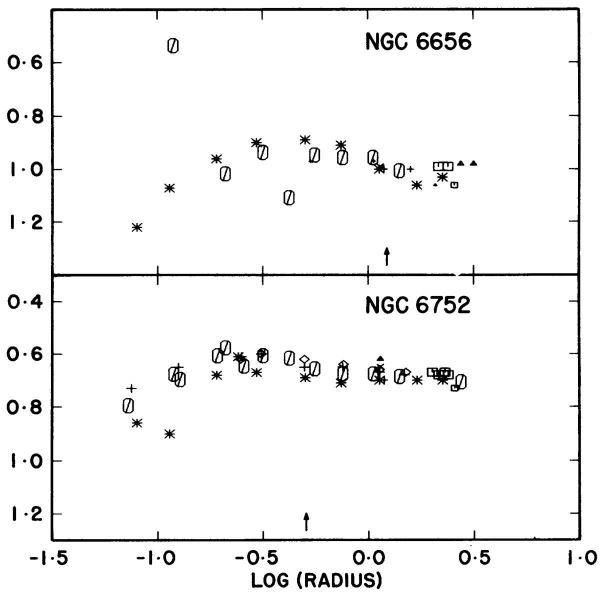

FIG. 3–The run of $(B-V)$ color index with radius of the observing aperture for NGC 6656 and NGC 6752. The symbol code is the same as for Figure 1(b).

field, and sometimes obvious evidence of differential or patchy interstellar absorption across the cluster position.

7. Only two of the six "post-collapse-core" clusters appear to have color gradients: NGC 6681 has a redder core and NGC 7099 has a bluer central region. A possible "post-collapse-core" cluster, NGC 6397, has a bluer core region.

8. Concentric aperture color gradients in $(B-V)$ thus appear to be best explained by statistical variations in the distribution of the brightest clusters stars and/or the brighter field stars superimposed on the cluster; color gradients are not evidence for radial variations in the intrinsic properties of the cluster stellar populations.

9. If radial population variations do exist in globular clusters, other techniques (spectroscopy, surface photometry) must be exploited to study their existence and properties.

10. To use concentric aperture photometry for determination of global colors of clusters, one must be aware that apparent radial color variations may be present. Additional color observations (not only in $(B-V)$) are needed for many clusters, including some of the brighter objects. A tabulation of $(B-V)$ color indices is given for 115 clusters and compared to other tabulations.

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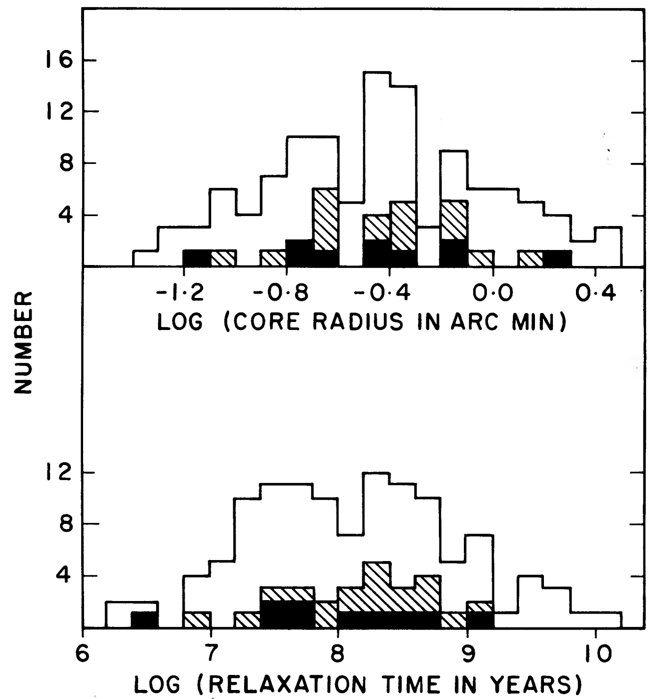

FIG. 4–Histogram distributions for the apparent core radii (top) and computed central relaxation times (bottom) of globular clusters, from the compilation of Webbink (1984). The solid line is the distribution for all clusters. The cross-hatched distribution represents the distribution of the 19 clusters with apparently redder centers. The filled-in distribution represents the ten clusters with apparently bluer centers.

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TABLE VIII

Concentric Aperture Photoelectric Photometry of Globular Clusters

Code	Author and Journal (In order of publication date)	# of Clusters	Type of Data*
SW	Stebbins, J., and Whitford, A. E. 1936, *Ap. J.* **84**, 132.	69	Pe,C_2
S	Stebbins, J. 1950, *M. N. R. A. S.* **110**, 416.	7	6-color
GB	Gascoigne, S. C. B., and Burr, E. F. 1956, *M. N. R. A. S.* **116**, 570.	2	PV
A	Arp, H. C. 1958, *A. J.* **63**, 118.	2	BV
DV	de Vaucouleurs, G. 1959, *Lowell Obs. Bull.* **4**, 105.	1	UBV
DB	Dufay, J., and Bigay, J.-H. 1959, *Comp. Rend.* **248**, 2162.	20	B-V
J	Johnson, H. L. 1959, *Lowell Obs. Bull.* **4**, 117.	27	UBV
KM	Kron, G. E., and Mayall, N. U. 1960, *A. J.* **65**, 58.	66	PVI
KR	Kron, G. E. 1961, unpublished; 1984, private communication.	21	PVI
GO	Gascoigne, S. C. B., and Ogston, R. A. 1963, *Observatory* **83**, 64.	2	BV
RO	Rousseau, J. 1964, *Ann. d'Ap.* **27**, 681.	19	UBV
G	Gascoigne, S. C. B., unpublished, quoted by Koehler, J. A. 1965, *Observatory* **85**, 197.	2	BV
MZ	Menzies, J. W., unpublished, quoted by Koehler, J. A. 1965, *Observatory* **85**, 197.	3	BV
KI	King, I. R. 1966, *A. J.* **71**, 276.	9	BV
KR	Kron, G. E. 1966, *Publ. A. S. P.* **78**, 143.	1	PVI
VDB	van den Bergh, S. 1967,*A. J.* **72**, 70; **75**, 131.	49	UBV
VDBH	van den Bergh, S., and Hagen, G. L. 1968, *A. J.* **73**, 569.	5	UBV
N	Neff, J. S. 1970, *M. N. R. A. S.* **149**, 45.	9	$m_{0.55}, \chi_1$
VDB	van den Bergh, S. 1971, *A. J.* **76**, 1082.	1	UBV
ZLK	Zaitseva, G. V., Lyutyi, V. M., and Kukarkin, B. V. 1974, *Soviet Astr.* **18**, 257.	26	UBV
HVDB	Harris, W. E., and van den Bergh, S. 1974, *A. J.* **79**, 31.	11	UBVr
R	Racine, R. 1975, *A. J.* **80**, 1031.	37	UBV
B	Bernard, A. 1976, *Astr. and Ap. Suppl.* **25**, 281.	5	UBV
I	Illingworth, G., and Illingworth, W. 1976, *Ap. J. Suppl.* **30**, 227.	10	BV
KG	Kron, G. E., and Guetter, H. H. 1976, *A. J.* **81**, 817.	65	6-color
RE	Rettig, T. W. 1976, unpublished Ph.D. Thesis, Indiana U..	4	UBV
C	Corwin, H. G. 1977, *A. J.* **82**, 193.	7	UBV
M	Mannery, E. 1977, unpublished.	5	BV
VDB	van den Bergh, S. 1977, *A. J.* **82**, 796.	5	UBV
CGHL	Canizares, C. R., Grindlay, J. E., Hiltner, W. A., Liller, W., and McClintock, J. E. 1978, *Ap. J.* **224**, 39.	1	UBVR
CF	Chun, M. S., and Freeman, K. C. 1979, *Ap. J.* **227**, 93.	24	UBV
DC	Da Costa, G. S. 1979, *A. J.* **84**, 505.	4	UBV
WB	West, R. M., and Bartaya, R. A. 1979, *Astr. and Ap. Suppl.* **38**, 69.	1	UBV
SWB	Searle, L., Wilkinson, A., and Bagnuolo, W. G. 1980, *Ap. J.* **239**, 803.	13	uvgr
Z	Zinn, R. 1980, *Ap. J. Suppl.* **42**, 19.	79	uvgr
VDB	van den Bergh, S. 1981, *Astr. and Ap. Suppl.* **46**, 79.	1	UBV
BP	Bica, E. L. D., and Pastoriza, M. G. 1982, *Astr. and Space Sci.* **91**, 99.	91	BV
GK	Gordon, K. C., and Kron, G. E. 1983, *Publ. A. S. P.* **95**, 461.	1	6-color
G	Gascoigne, S. C. B., unpublished, quoted by Gordon, K. C., and Kron, G. E. 1983, *Publ. A. S. P.* **95**, 461.	1	BV
H	Hamuy, M. 1984, *Astr. and Ap. Suppl.* **57**, 91; M.S. Thesis, University of Chile; and private communication.	84	UBVRI
HA	Hanes, D. A. 1984, *Proc. Astron. Soc. Australia* **5**, 360.	31	UBV
HB	Hanes, D. A., and Brodie, J. 1985, *M. N. R. A. S.* **214**, 491.	71	UBVRI
CJP	Peterson, C. J. 1985, this study.	102	BV

*Notes to TABLE VIII: Conversion of Color Data to the $(B-V)$ System.

Gascoigne and Burr (1956): Their $(P-V)$ has been converted to $(B-V)$ via the relation given in their paper,

$$(B-V) = 0.91\,(P-V) + 0.16 \quad .$$

For NGC 104, this results in a $(B-V)$ color index which is systematically too blue by ~ 0.08 magnitude compared to the average of all other color measurements. Data for NGC 5139 are better, differing from the average of other $(B-V)$ measures by only ~ 0.01 magnitude.

Kron (1966), Kron (unpublished), and Kron and Mayall (1960): $(P-V)$ color indices have been converted to $(B-V)$ via the relationship given in van den Bergh (1967),

$$(B-V) = 0.07 + 1.07\,(P-V) \quad .$$

Stebbins and Whitford (1936): Their color index C_2 has been converted according to Kukarkin (1974),

$$(B-V) = (2.748 \pm 0.072)\,C_2 + (0.883 \pm 0.009) \quad .$$

Stebbins (1950) and Kron and Guetter (1976): The $[V-G]$ color index

NOTES TO TABLE VIII (continued)

from six-color photometry has been used to obtain $(B-V)$ color indices on the standard system by use of the relation of Morgan, Harris, and Johnson (1953) which applies to the light of yellow giant stars,

$$(B-V) = (0.697 \pm 0.008) + (0.716 \pm 0.011\,[V-G] \quad ,$$
$$0.3 < [V-G] < 1.2,\ 0.9 < (B-V) < 1.5 \quad .$$

This produces $(B-V)$ values $((B-V) \sim 0.6)$ for the four clusters of Stebbins in excellent agreement with measurements by other observers. For the data of Kron and Guetter, we find good agreement between $(B-V)$ values obtained with this equation and the mean $(B-V)$ color indices obtained by averaging the measurements of all other studies only for $(B-V) \leq 1.0$:

$$(B-V)_{KG} - \langle B-V \rangle = -0.003 \pm 0.005 \text{ (44 clusters)} \quad .$$

For $(B-V)_{KG} > 1.0$, there is a systematic difference of the form

$$(B-V)_{KG} - \langle B-V \rangle = 0.268 - 0.269\,(B-V)_{KG} \quad .$$

Thus, for clusters redder than $(B-V) = 1.0$ $[V-G] > 0.42)$ we have used the conversion relation,

$$(B-V) = 0.909\,[V-G] + 0.616$$

which follows from the above. For these clusters, we then have

$$(B-V)_{KG} - \langle B-V \rangle = 0.000 \pm 0.006 \text{ (2 clusters)} \quad .$$

Gordon and Kron (1983) give the following transformation

$$(B-V) = 0.672 + 0.813\,[V-G]$$

valid for $(B-V) \leq 0.90$, based on observations of standard stars. This relation produced $(B-V)$ values somewhat redder than the equation derived here.

Zinn (1980) and Searle, Wilkinson, and Bagnuolo (1980): The $(g-r)$ color from the Gunn intermediate-band photometric system (Thuan and Gunn 1976) was used to calculate $(B-V)$ color indices via the relationship

$$(B-V) = 0.4529 + 0.8061\,(g-r)$$

which differs from the calibration that was used by van den Bergh (1981).

Neff (1970) Visual magnitudes have been computed from the intermediate-bandpass photometry via the relation of Neff and Travis (1967),

$$V = m_{0.55} + (0.0712 \pm 0.0002)\,\chi_1 \quad .$$

Comparison of χ_1 with mean $(B-V)$ color indices gives the transformation equation,

$$(B-V) = 0.021 + 1.345\,\chi_1$$

with an rms error of 0.04 magnitude.

TABLE IX

Clusters with Apparent Radial Color Variations

Clusters with redder centers		
NGC 362	NGC 6273	NGC 6584
2808	6333	6638
3201 ?	6355	6681
5024	6362	6712
5634	6388	6838
5904	6553	6934 ?
6171		
Clusters with bluer centers		
NGC 1904 ?	6397	NGC 6809
2298 ?	6402 ?	7089
6266	6637	7099
6284		

TABLE IX: Notes on Individual Clusters.

NGC 362: Chun and Freeman (1979) noted the redder central region. Bendinelli *et al.* (1983) found that giants dominate the projected stellar distribution in the central region of the cluster, but no color gradient was apparent outside the cluster center in agreement with the concentric aperture photometric data.

NGC 1904: Data are sparse for $\log r < -0.50$. This is not a strong case for a redder core.

NGC 2298: Much scatter in the data. We find $(B-V) = (0.805 \pm 0.019) + (0.059 \pm 0.041) \log r$ with an rms error of the fit of 0.077 magnitude.

NGC 2808: Chun (1981) finds a radial CN and a possible G-band variation. On the other hand, Forte and Mendez (1984; see also Caloi and Castellani 1983) point out that there is an unresolved red image $((B-V) \sim 2.3 \pm 0.5)$, either a field star, a cluster star in a post-giant evolutionary

TABLE IX (continued)

phase, or a compact clump of cluster giants, only 3″ northeast of the center of symmetry. This object alone can account for the apparent radial change of color found in the concentric aperture data which is confirmed by coversion of the concentric aperture data to color within annuli: the only real color variation occurs for $r < 8''$.

NGC 3201: There is scatter for small-aperture observations which may be due to the tendency to set the telescope on a specific bright star in this rather open and diffuse cluster. Overall, $(B-V) = (0.957 \pm 0.010) - (0.036 \pm 0.023) \log r$ with an rms error for the fit of 0.054 magnitude.

NGC 5024: The redder core was noted by Chun and Freeman (1979). Rejecting several data more than $2.5\,\sigma$ from the mean relation, we find $(B-V) = (0.650 \pm 0.005) - (0.026 \pm 0.012) \log r$. Cuffey (1966) concluded that this cluster is an anomalous case with the central red giants bluer than those in the outer region of the cluster which would give an expected color gradient in the opposite sense than found here. While Cuffey's data do suggest a larger proportion of central red giants, his color transformations for the photographic iris photometry are probably affected by the unresolved background light from faint cluster stars.

NGC 5634: A distinctive case which is not a good candiate for a linear color fit. The two largest aperture measurements of Hanes and Brodie (1985) are contaminated by the light of SAO 139967, only 1.′3 from the cluster center, $V \sim 8.0$, $(B-V) \sim 1.5$. The small number of resolved stars in this cluster give the impression that the brightest red giants are crowded to the cluster center.

NGC 5904: Buonanno *et al.* (1981) concluded that a few red giants explain the apparent color gradient pointed out by Chun and Freeman (1979). The gradient is thus not a collective property of the cluster stars.

NGC 6171: Dickens and Rolland (1972) found that the red giants are more concentrated to the center than are horizontal-branch stars, which they attributed to mass loss and stellar relaxation effects; however, more recent calculations of the central relaxation time (Peterson and King 1976; Webbink 1984) suggest that the relaxation time is longer than the stellar evolution time scale.

NGC 6266: A least-squares fit (excluding three extraneous data) gives $(B-V) = (1.171 \pm 0.005) + (0.047 \pm 0.011) \log r$ with an rms error for the fit of 0.026 magnitude. The color gradient, however, may be due to differential reddening across the cluster (Alcaino 1978).

TABLE IX (continued)

NGC 6273: Color data are somewhat scattered, but $(B-V) = (1.037 \pm 0.010) - (0.108 \pm 0.022) \log r$ for all data. The cluster has a relatively low central concentration, a large ellipticity in its projected stellar distribution, and exists in a fairly dense star field with probable differential absorption across its position (Harris, Racine, and de Roux 1976).

NGC 6284: Neglecting two discordant data, $(B-V) = (1.008 \pm 0.004) + (0.025 \pm 0.007) \log r$. Although the central relaxation time is short ($T_r \sim 3.2 \times 10^7$ years), the central color is bluer than the overall cluster.

NGC 6333: Color trend is apparent in spite of scatter in the data.

NGC 6355: The cluster is in a crowded field with obvious differential absorption across the position of the cluster.

NGC 6362: A very open cluster, the brightest stars have a very patchy distribution in the center of the cluster.

NGC 6388: The shift toward a bluer color for the largest apertures is due to inclusion of a bright blue star (star No. 18 of Evans and Menzies 1977) located 1.′6 from the cluster center. Forte and Mendez (1984) found no color gradient in the central region of the cluster; their color derived from Reticon observations is 1.10–1.15 in $(B-V)$, somewhat bluer than indicated by the concentric aperture data.

NGC 6397: Woolley *et al.* (1961) found that the blue stars and the red giants have the same spatial distribution. Auriere (1982) found a central clump of faint blue stars which can account for all the color variation in this cluster. This is a possible "post-collapse-core" cluster (Djorgovski and Penner 1984).

NGC 6402: A somewhat open cluster with a patchy distribution of bright stars in the cluster core.

NGC 6553: There is a distressingly large scatter in the data. The cluster is diffuse and open with patchy interstellar absorption in front. The inner region may be redder because of the presence there of the few brightest red giants in the cluster. The outermost data are bluer due to a single star at $r \sim 0.'8$ with $V \sim 10$ (cf. Hartwick 1975).

NGC 6584: The center appears much redder than the outer region, although a shallower color gradient persists to the largest observed radius. The brightest stars have a very patchy distribution in the cluster.

NGC 6637: $(B-V) = (1.021 \pm 0.007) + (0.042 \pm 0.013)$.The central distribution of bright stars is very patchy.

NGC 6638: $(B-V) = (1.140 \pm 0.007) - (0.082 \pm 0.014) \log r$. The cluster is found in a very crowded field.

NGC 6681: This is a "post-collapse-core" cluster (Djorgovski and Penner 1984), only one of two such clusters which appear to have a color gradient.

NGC 6712: The distribution of bright stars is very patchy and the cluster is found in a very crowded field; thus, it is not surprising that a color gradient is found.

NGC 6809: $(B-V) = (0.693 \pm 0.007) + (0.053 \pm 0.013) \log r$. This is a large cluster with a large core radius (1.′7) and a patchy distribution of the brightest stars.

NGC 6838: The redder center is apparent in spite of the large scatter in the data. The measurements through the smallest apertures are essentially the light of a single star (star H, $V = 12.08$, $(B-V) = 1.84$, of Arp and Hartwick (1971)). The bluer measurements from the largest apertures are affected by star N of Arp and Hartwick, $V = 10.13$, $(B-V) = -0.10$, located 2.′5 north of the cluster center. Out to this radius, the cluster magnitude is $V \sim 8.5$.

NGC 6934: The largest apertures of Hanes and Brodie (1985) include a bright star 1.′9 west of the cluster center, $V = 9.25$, $(B-V) = 1.12$ (Harris and Racine 1973). The cluster red giants seem to be concentrated to the cluster center.

NGC 7089: Some scatter in the data for this cluster which is open and difficult to center in an aperture at the telescope. Strauss (1978) found no significant color gradient on the basis of strip (6.″3 × 8′ aperture) photometry. Auriere and Cordoni (1983) found a large variation in $(B-V)$ (0.55 to 0.70) in the center due to the statistical distribution of red-giant stars.

TABLE IX (continued)

NGC 7099: The second "post-collapse-core" cluster in this sample (Djorgovski and Penner 1984). Williams and Bahcall (1979) suggested the cluster becomes redder with increasing radius, with a change of 0.33 ± 0.33 magnitude in $(B-V)$ out to 2′. Alcaino and Wamstecker (1982) found a central deficiency of blue horizontal-branch stars in the central region which they attributed to mass loss and subsequent mass stratification of stars in the cluster; but this would tend to produce a color gradient opposite to what is observed. The central blueness was first pointed out by Zinn (1980). Zinn and West (1984) find unusually strong hydrogen lines in spectra of the cluster center which they believe is causally connected to the color gradient. The gradient is not due to a radial metallicity color gradient in the cluster, but must be associated with a greater frequency of some type of blue star in the cluster center.

TABLE X

B-V Color Indices for Globular Clusters

Cluster NGC	Harris and Racine (1979)	Reed (1984)	This Study
104	0.89	0.88	0.88
288	0.66	0.65	0.66
362	0.76	0.77	0.78
1261	0.70	0.72	0.70
0432-21			0.79
Pal 2	1.9:	2.08	2.05
1841		0.96	0.86
1851	0.78	0.75	0.76
1904	0.63	0.65	0.64
2298	0.73	0.77	0.78
2419	0.66	0.73	0.66
2808	0.93	0.92	0.90
3201	0.98	0.96	0.97
Pal 4	0.80*		
4147	0.60	0.59	0.59
4372	0.97:	1.04	1.10
4590	0.63	0.63	0.62
4833	0.96	0.93	0.96
5024	0.64	0.65	0.65
5053	0.64	0.66	0.63
5139	0.79	0.78	0.80
5272	0.69	0.69	0.69
5286	0.87	0.88	0.89
5466	0.71	0.73	0.67
5634	0.67	0.67	0.68
5694	0.69	0.69	0.70
IC 4499	0.88	0.82	0.91
5824	0.75	0.75	0.75
Pal 5	0.70*		
5897	0.75	0.70	0.74
5904	0.71	0.72	0.71
5927	1.31	1.30	1.30
5946	1.24	1.29	1.29
5986	0.90	0.89	0.89
6093	0.85	0.83	0.84
6101	0.68:	0.68	0.69
6121	1.03	1.00	1.03
6139	1.39	1.40	1.40
6144	1.01	0.96	0.95
6171	1.14	1.21	1.10
6205	0.69	0.68	0.67
6218	0.82	0.84	0.83
6229	0.71	0.71	0.72
6235	1.04	1.05	1.05
6254	0.92	0.90	0.89
6256	1.68	1.69	1.68
6266	1.17	1.16	1.19
6273	1.00	1.03	1.01
6284	0.95	0.99	1.01
6287	1.20:	1.20	1.21
6293	0.98	0.96	0.96
6304	1.33	1.31	1.33
6316	1.27	1.39	1.40
6325	1.54:	1.66	1.67
6333	0.94	0.97	0.97
6341	0.62	0.64	0.62
6342	1.29	1.26	1.28
6352	1.06	1.06	1.08
6355	1.46	1.48	1.45
6356	1.11	1.13	1.13

TABLE X (Continued)

Cluster NGC	Harris and Racine (1979)	Reed (1984)	This Study
6362	0.85	0.88	0.85
6366	1.47	1.44	1.46
6380		2.04	2.01
6388	1.17	1.17	1.18
6397	0.75	0.68	0.73
6401	1.58	1.67	1.58
6402	1.28	1.25	1.27
Pal 6		2.83	2.84
6426	1.03	1.02	1.04
Trz 5	2.77	2.77	2.77
6440	1.98	1.97	1.98
6441	1.28	1.27	1.27
6453	1.28	1.31	1.33
6496	0.93	0.94	0.98
6517	1.79	1.75	1.76
6522	1.22	1.21	1.21
6528	1.45	1.53	1.52
6535	0.97	0.94	0.94
6539	1.89	1.78	1.83
6541	0.77	0.76	0.75
6544	1.36	1.46	1.44
6553	1.62	1.64	1.73
6558	1.09	1.10	1.10
IC 1276	1.74	1.76	1.76
6569	1.34	1.34	1.34
6584	0.79	0.81	0.76
6624	1.10	1.11	1.11
6626	1.10	1.08	1.08
6637	0.99	1.01	1.02
6638	1.16	1.15	1.15
6642	1.08	1.11	1.09
6652	0.92	0.89	0.94
6656	0.99	0.98	0.99
Pal 8	1.19	1.22	1.22
6681	0.71	0.72	0.72
6684		0.98	0.98
6712	1.16	1.17	1.15
6715	0.85	0.85	0.85
6717	0.93	1.03	1.00
6723	0.75	0.75	0.77
6749	1.76:	2.21	2.14
6752	0.65	0.67	0.67
6760	1.66	1.66	1.68
6779	0.86	0.89	0.86
6809	0.69	0.68	0.72
Pal 11			1.27
6838	1.13	1.14	1.09
6864	0.87	0.87	0.87
6934	0.74	0.77	0.75
6981	0.72	0.72	0.74
7006	0.74	0.72	0.75
7078	0.68	0.68	0.68
7089	0.67	0.66	0.67
7099	0.58	0.57	0.60
Pal 12	0.90	1.07	1.05
Pal 13	0.69:	0.72	0.73
7492	0.48	0.42	0.42

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APPENDIX

A referee has recommended strongly that data be displayed for several other clusters which have been identified by previous observers as having color gradients. Data for NGC 104, NGC 5139, NGC 5272, NGC 6440, NGC 6624, and NGC 7006 are shown in Figure 5 where the identification code for the symbols is the same as that of the other figures. The reader thus can directly make his or her own evaluation of the evidence for or against a color gradient.

To facilitate the goals of assisting other researchers in making their own independent judgment of the available data as well as to allow ready use of these data for other studies of globular-cluster properties, a data file of all photoelectric photometry has been compiled. This file now includes not only the $(B-V)$ data used in this study, but also integrated visual magnitudes and $(U-B)$, $(V-R)$, and $(V-I)$ measurements. A copy of the data file on magnetic tape is available either from the author or from the NASA Data Collection Center at Greenbelt, Maryland.

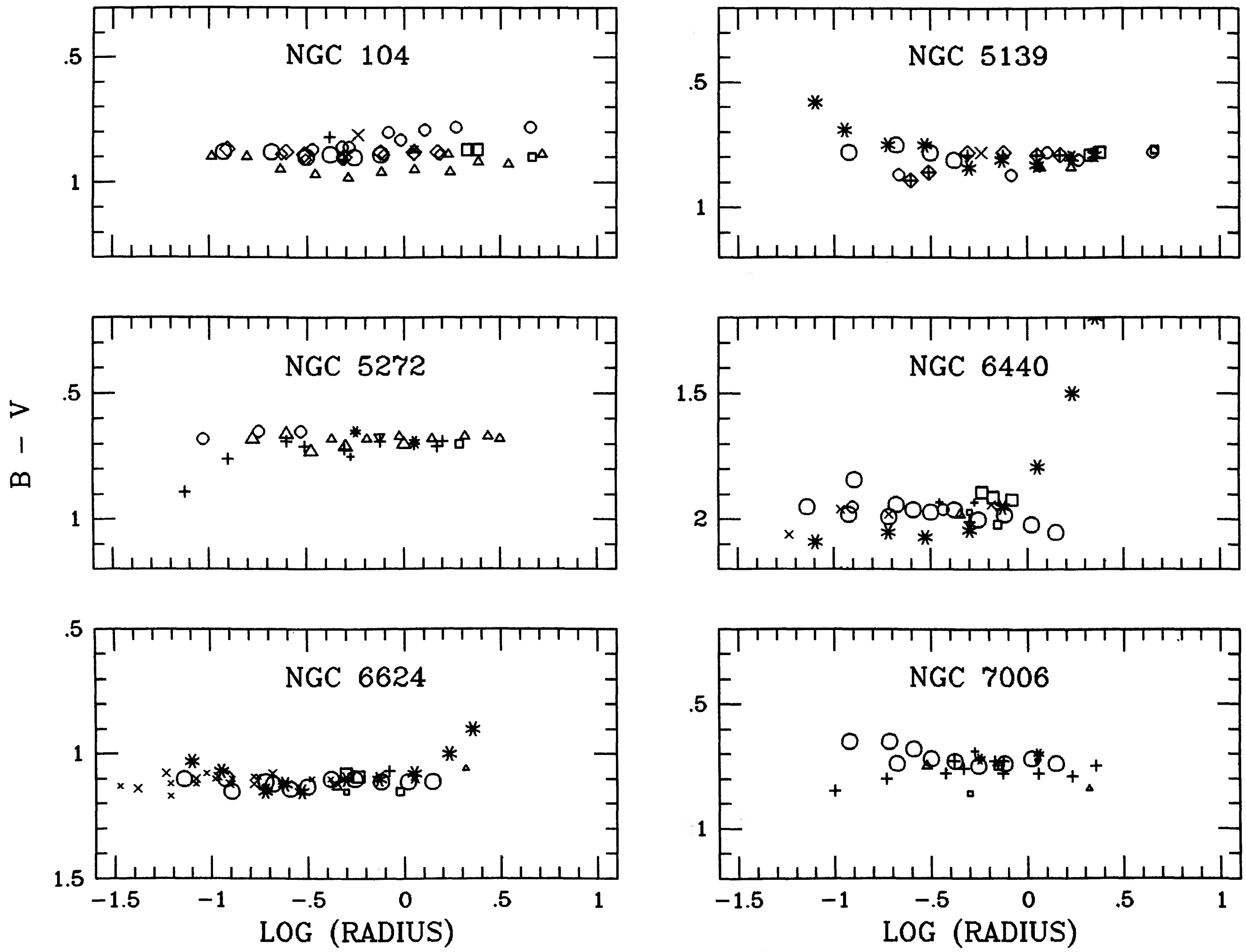

FIG. 5–The run of $(B - V)$ color index with radius of the observing aperture for six clusters in which the combined data of all observers does not support the inferred existence of a radial color gradient. A color gradient in NGC 104 was suggested by Chun and Freeman (1979) on the basis of photoelectric spot measurements; these authors also found redder centers in NGC 5139, NGC 5272, and NGC 7006 based on their concentric aperture photometry. Surface photometry by Martins *et al.* (1980) and Harvel and Martins (1977) had suggested bluer and redder cores, respectively, in NGC 6440 and NGC 6624.