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New determinations of R in open clusters

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New variable-extinction analyses for 51 galactic clusters, using primarily zero-age main-sequence-fitted data, are presented and discussed. For three of these clusters new spectroscopic data for the brighter stars are presented. The weighted mean value of R, the ratio of total to selective extinction, for all 51 clusters is 3.08 ± 0.03 s.e., in very good agreement with the results of other determinations listed in Table IV. Careful examination of the data for individual clusters suggests that some evidence for a dependence of R on intrinsic color and galactic longitude may be present.

INTRODUCTION

A KNOWLEDGE of R, the ratio of total to selective extinction, is fundamental for the determination of distances in the Galaxy. Consequently, a variety of methods have been used in the past to estimate the value of this ratio. Briefly, these methods include spectrophotometric studies (principally the color-difference method), comparisons of radio and Balmer line emission from H II regions, kinematic studies of young objects, two-color extinction measurements of dark nebulae, the method of cluster diameters, and the variable-extinction method. The last has the advantage of being simple to apply, and of yielding values of R which apply to localized regions of space. In most of the other methods the derived value is an integration of R over the entire line of sight. This distinction can be important when comparing results from the various methods.

In variable-extinction analyses the fundamental principle is that, for a group of stars at a common distance affected by different amounts of interstellar extinction, a plot of apparent distance modulus $V - M_V$ versus color excess E_{B-V} should show a correlation, the slope of which is R. As shown by Becker (1966) and Garrison (1970), bias towards large values of R can occur if nongroup members (foreground or background stars) are accidentally included in such an analysis. This often arises in the study of OB associations, since it is possible for several distinct groups of OB stars to be present in the large area of sky covered by a typical association. For distant young clusters, however, this situation occurs much less frequently owing to the small area of sky they cover and the low space density of young OB stars. On the other hand, it is generally found that the spread in E_{B-V} exhibited by stars in clusters is much smaller than that occurring in OB associations. In situations such as this, Becker (1966) has suggested that bias in the resultant values of R can arise due to the presence of random scatter in cluster color–color diagrams. However, a reanalysis of this problem by Turner (1976) has demonstrated that random scatter of the data points in cluster color–color diagrams is generally unimportant in such cases, and also that clusters for which the spread in E_{B-V} is small *can* be used to obtain reliable estimates of R. In this paper we intend to further demonstrate the validity of both these conclusions by presenting the results of new variable-extinction analyses for 51 clusters, all of which yield acceptable values of R.

I. METHOD OF ANALYSIS

The data necessary for variable-extinction analyses of young clusters are intrinsic colors and absolute magnitudes for member stars. These are usually derived using spectral classifications of individual stars, but with the lack of such data in the case of distant clusters, are also estimated by individually dereddening the observed colors for cluster stars and then forcing a fit to the zero-age main sequence (ZAMS). It is this latter technique which was criticized by Becker (1966), owing to the bias which results if random scatter is present in the data. According to the results of Turner (1976), however, such bias is unimportant provided that good quality photometry is used and provided that differential reddening dominates in the resultant variable-extinction diagram. According to the results of Burki (1975) and the discussion by Turner (1976), a minimum spread in E_{B-V} of about 0.20 is necessary to insure that this latter condition is fulfilled. This restriction is met by all but one of the clusters studied in this paper.

The method of ZAMS fitting can lead to poor results if one uses only a small number of stars in the analysis or if one does not discriminate against the accidental inclusion of multiple systems and evolved cluster members. These problems have been avoided here by using at least ten cluster stars in each individual determination of R and by restricting the analyses to "lower envelope data." The method of using the lower envelope to discriminate against multiple systems and evolved stars has been discussed previously by Turner (1973, 1976). A good example illustrating its importance is provided by the following analysis of the well-studied cluster surrounding α Persei.

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The α Persei cluster has been observed on the *UBV* system by Harris (1956) and Mitchell (1960), and on the *uvby* system by Crawford and Barnes (1974). Crawford and Barnes noted the possible existence of a systematic error in Mitchell's $U - B$ values, so estimates of the intrinsic $B - V$ colors for cluster stars were made here using Crawford and Barnes' estimates of $E(b - y)$ and the relation $E(b - y) = 0.70\ E_{B-V}$. ZAMS values of M_V were assigned to each star for which $(B - V)_0 \leq 0.40$, where the ZAMS used is the relation of Vogt (1971) for h Persei fitted to the OB star relation of Turner (1976). The resultant values of $V - M_V$ and E_{B-V} for 62 cluster stars are plotted in Fig. 1.

The likelihood of cluster membership for these 62 stars is based mainly on the results of the proper motion study of Heckmann, Dieckvoss, and Kox (1956). For 50 of these stars there are additional radial velocity data (Petrie and Heard 1970) on which to base membership. Unfortunately, it is difficult to discriminate against background stars in this region on the basis of these data. Accordingly, the five stars of large color excess in Fig. 1 which lie apart from the other stars were considered likely to be background objects, and were eliminated from the analysis. Using the lower-envelope method one can further eliminate a group of 11 stars of spectral types B8 or earlier (classifications from Morgan, Hiltner, and Garrison 1971) as likely non-ZAMS objects, and nine stars as likely multiple systems. For six of these nine stars the radial velocity data confirm duplicity. In some cases the effect is negligible and clearly has little influence on the derived value of R (star 692, for example, is a confirmed spectroscopic binary, but it falls very close to the lower-envelope relation in Fig. 1). However, when evolution or multiplicity do significantly influence the estimate of $V - M_V$ for a star, R can be affected. In the present study we find 37 stars which best define the lower envelope. Even though the range of color excess for these 37 stars is small (0.20) a regression analysis yields quite reasonable values of $R = 3.2 \pm 0.26$ p.e. and $V_0 - M_V = 6.02 \pm 0.03$ p.e. If the rejected stars had been included in the analysis, however, the resultant value of R would be significantly larger than 3.2. This may explain why Heard and Petrie (1967) derived $R = 4$ in their study of this cluster. The data for cluster stars presented in Fig. 1, however, provide little evidence for the existence of so large a value of R. The use of the lower-envelope method for analyzing this cluster therefore leads to a more satisfactory solution than is obtained otherwise.

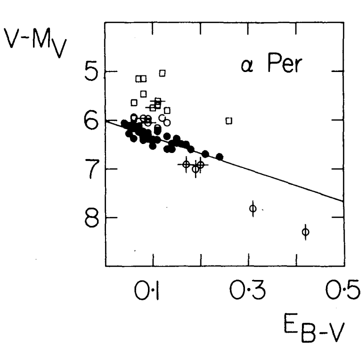

FIG. 1. Variable-extinction diagram for the α Per cluster. The various symbols used to designate the stars are as follows: (1) filled circles—lower-envelope stars from the ZAMS fit (from which the indicated slope of $R = 3.2$ was derived), (2) open circles—stars considered as likely binaries or background objects (the latter are indicated by vertical lines through the symbols), (3) squares—likely evolved objects, (4) horizontal lines—known spectroscopic binaries.

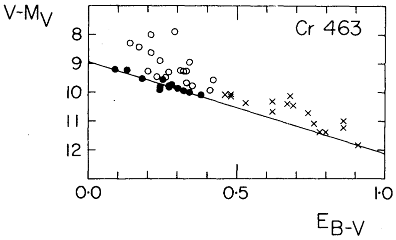

FIG. 2. Variable-extinction diagram for Cr 463. The indicated relation of slope $R = 3.2$ was derived using the lower-envelope stars from the ZAMS fit (filled circles). Stars designated by open circles were considered to be likely multiple systems or non-ZAMS objects. Stars with ambiguous reddening solutions are denoted by crosses.

Problems with the ZAMS-fitting method can arise from improper reddening corrections. Curvature in the intrinsic color–color relation makes it possible for some stars to have two or three reddening solutions when dereddening is attempted. For the clusters studied here, however, it was possible to use available spectroscopic data and stars with unique reddening solutions to determine the true range of E_{B-V} for cluster stars. For stars with multiple reddening solutions, the one adopted was that giving a value of E_{B-V} in this range. Where distinct ambiguities arose, the star was simply ignored. Foreground stars could often be identified in this manner, while background stars proved to be extremely rare in the clusters studied.

A good example of a spurious value of R resulting from improper reddening corrections is provided by the data for Cr 463. Townsend (1975) has derived a value of $R = 3.04$ for this cluster using his *UBV* observations for probable member stars. In his analysis, a spread in E_{B-V} of about 0.8 was found for cluster stars, which were all dereddened to the B-star relation. That this solution cannot be valid is demonstrated by two pieces of evidence: (1) On the POSS prints there is no evidence for patchy extinction in or around this cluster, which is unusual if the amount of differential reddening is really as large as 0.8, and (2) the range of E_{B-V} for 19 stars with unique reddening solutions is only 0.33. A reanalysis of Cr 463 is presented in Fig. 2. Crosses in this diagram indicate stars for which the reddening solution is likely to be invalid. Many of these stars are probable foreground objects, while others may be cluster members which have companions or are slightly evolved. For the 13 stars of small color excess which best define a lower envelope, the resultant value of R is 3.2 ± 0.25 p.e., not appreciably different from Townsend's result. It is interesting to see how the inclusion of improperly dereddened objects, non-ZAMS stars, and possible multiple systems can leave unaffected the derived value of R for this cluster. Tests on a few other clusters studied in this paper, however, showed that improper dereddening could have a significant effect on the derived R value.

The reddening corrections applied in this paper (with the exception of those for α Per and Mel 101) were made using individual values of $X = E_{U-B}/E_{B-V}$ found from OB stars in the region of each cluster. This procedure was followed because (1) observational evidence (Wampler 1964; Turner 1973, 1976) suggests that linear reddening relations are more appropriate for early-type stars than the curved relations predicted by theory, (2) although some studies (Serkowski 1963; FitzGerald 1970) suggest that X may vary strongly with spectral class for the B stars, this dependence is not predicted by theory and may be simply a phenomenon associated with the treatment of an inhomogeneous sample of data (the MK classifications for B stars) by the least-squares method.

The variable-extinction analyses were performed using mainly data from ZAMS fitting (as described for α Per); however, spectroscopic data were also used in some cases where few ZAMS objects could be found. The resultant values of R were derived from regression analyses, with the solutions being weighted according to the expected errors in $V - M_V$ and E_{B-V}. Since an error in E_{B-V} of ± 0.01 will lead to an error in $V - M_V$ which is $\geq \pm 0.045$ (Turner 1976), a weight ratio of 20:1 was considered appropriate for this study. Use of a higher ratio would lead to a small systematic decrease in the resultant values of R.

II. PHOTOMETRIC AND SPECTROSCOPIC DATA

The *UBV* data for each cluster were taken from the literature, with the principal source being the U. S. Naval Observatory Catalogue (Hoag *et al.* 1961). Stars at the faint end (V = 15–16) of many of these clusters were ignored in the analyses, however, when the presence of trends in the variable-extinction data suggested that systematic errors may be present in the photometry for these stars (most likely in the $U - B$ values).

Available spectroscopic data were used mainly to decide on the true range of E_{B-V} for cluster stars, and only occasionally to gain additional data for the variable-extinction analyses. The spectroscopic data were not always useful for deriving absolute magnitudes and intrinsic colors for two reasons: (1) Large uncertainties in M_V and $(B - V)_0$ are associated with some MK classes (late B giants, for example), and (2) inhomogeneities arising from lack of proper spectral widening and possibly inadequately dense exposures for the spectrograms in some studies of faint cluster stars lead one to suspect that systematic errors in classification may be present for stars fainter than 11.5 in B.

New data for three clusters are presented in Table I. These consist of spectral types derived from spectrograms obtained using the Cassegrain spectrograph on the University of Western Ontario 1.2-m telescope. For these observations a reciprocal dispersion of 315 Å/mm was used along with a projected slit width of 20 μ and a minimum widening for the faintest stars of 0.2 mm. The spectra, which were recorded on 103a-0 plates developed in D-19, were classified by comparison with a detailed grid of MK standards obtained with the same instrument (Turner 1974). Classification was made difficult by the fact that only the strong stellar lines stand out at this dispersion, but was also simplified somewhat by the use of line blends which are more prominent at lower dispersion (Morgan, see Abt 1963), and by the intercomparison of cluster stars. With some practice the basic temperature classes could easily be discerned, while for early-type stars the hydrogen lines proved to be very sensitive indicators of luminosity class. The resultant spectral types from this program (Turner 1974) for stars brighter than B = 11 were generally within one subclass in temperature and luminosity of the quoted MK types. For stars fainter than B = 11, however, discrepancies with respect to the classifications of Hoag and Applequist (1965) were noticeable. The nature of these discrepancies is illustrated by the comparison in Table I of 315-Å/mm spectral types (Tnr) with Hoag and Applequist spectral types (HA).

It seems unlikely that the differences in spectral classification for stars in Table I could be due to spectral variability or misidentification. Clearly, the cause goes deeper, and in this regard it is important to note the following points: (1) for good quality spectral classification work an optimum spectral widening to dispersion ratio is recommended; for the faint stars observed by HA the adopted widening of 0.1 mm is much less than the optimum widening of 0.9 mm; (2) roughly half of the stars in Table I classified by HA have uncertain spectral classifications (this usually implies that the spectrograms were not adequately exposed); and (3) for stars common to the two surveys, a comparison of the 315-Å/mm spectra with standards of the quoted HA spectral types often revealed marked differences in observable spectral features (for example, stars 3, 53, and 97 in NGC 654). These points suggest that it would be well to regard the HA spectral classifications for faint cluster stars with some suspicion. Consequently, although spectroscopic observations were frequently available for the clusters studied here, it was considered safer in most instances to base the variable-extinction analyses on ZAMS-fitted data.

III. RESULTS

The results of these analyses for 51 clusters are presented in Table II, and illustrations for 47 of these are given in Figs. 1–11. Results for the Pleiades are illustrated in Fig. 3 of Turner (1976a), while those for NGC

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TABLE I. Spectral types in three clusters.

Star[a]	B	Spectral type Tnr	Spectral type HA	E_{B-V}	$V-M_V$	M_{V_0}	Remarks
				NGC 654			
1	8.6	F5 Ia	...	0.87	...	−7.46	MK std HD 10494
2	10.4	A2 Ib	A0 Ib	0.83	14.56	−5.02	BD +61° 315
3	12.2	B1.5 IV	B6:V	0.94	14.98	−3.41	
11	12.4	B1 V	...	0.93	14.94	−3.13	
23	12.8	K2 IV:	...	0.14:	...	...	Foreground star
33	12.8	B2 IV	...	0.94	15.15	−2.74	
41	11.6	B2 II	...	1.06	15.53	−4.51	
53	12.0	B1 V	B5 V	0.87	14.60	−3.29	
97	12.4	B1.5 V	B6:V	0.80	14.54	−2.65	
101	12.8	B1 V	...	0.83	14.36[b]	−2.35	
102	11.8	B2 IV	...	0.78	14.22	−3.21	
				NGC 6830			
1	9.3	B9.5 II	B9.5 III	0.32	...	−2.87	BD +22° 3837
2	10.2	B5 III	B7:V	0.44	...	−2.42	BD +22° 3834
3	10.8	B6 IV	B9:III:e	0.52	...	−2.11	
4	11.5	F9 V:	...	0.05	...	...	Foreground star
5	11.6	A9 III:	...	0.37	...	−1.10	
6	11.6	B7 III	A0 V	0.54	...	−1.42	
7	12.1	B6 IV	B6:V	0.56	...	−0.96	
8	12.4	B6 IV	B6:V	0.56	...	−0.66	
10	12.6	B6 IV	...	0.63	...	−0.73	
27	11.6	B5 IV	...	0.54	...	−1.36	
28	12.0	B7 IV	...	0.47	...	−0.77	
				NGC 6834			
1	8.6	...	A3 V	0.04	...	...	Foreground star
2	10.5	F0 Ib	...	0.68	...	−4.17	BD +29° 3779
3	10.7	B5 III	B5 IV	0.49	...	−2.87	
5	11.8	F2 V	...	0.06	...	...	Foreground star
6	12.3	F8 V	...	0.12	...	...	Foreground star
7	12.5	B5 III	...	0.77	...	−2.12	
10	13.0	...	B5 V	0.62	...	−1.04	
28	11.6	B5 III	...	0.64	...	−2.53	
29	12.4	B6 III	...	0.78	...	−2.30	

[a] Numbering for NGC 654 according to Pesch (1960), otherwise according to Hoag *et al.* (1961).
[b] ZAMS value of M_V used, otherwise $V-M_V = 15.43$.

2264 are given in Turner (1976b). The interesting results for NGC 6611 and IC 1805 will be presented elsewhere. Table II also gives information on the number of stars used in the analysis (n), the equivalent spectral type of the bluest stars on the ZAMS (sp), and the average intrinsic color $[(B-V)_0]$ and spread in color excess (ΔE_{B-V}) for cluster stars. Comments on the results for a few interesting clusters are presented below.

The large variation of reddening found for stars in NGC 129 is unusual considering that only moderate patchiness is visible on the POSS prints for the region of this cluster. It is noteworthy, however, that the stars of small color excess all lie at the cluster extremes, while those of large color excess are found close to the cluster center. The majority of cluster stars have a total range in color excess of only 0.4, which is more typical of the clusters studied in this paper.

The data of Table I were used to supplement the ZAMS data in the analysis of NGC 654. The resultant values of intrinsic absolute magnitude derived for stars in this cluster as well as for stars in NGC 6830 and NGC 6834 are given in column 7 of Table I. The results for these last two clusters should prove useful for calibrating the absolute magnitude–spectral type relation for late B giants.

The data for Mel 101 were derived by analyzing the Cape U_cBV observations using the Q method (Braes 1962), This type of analysis appears to give reasonably good results for this cluster. All stars here have unique reddening solutions.

The present value of $R = 2.9$ derived for NGC 6193 is appreciably different from Herbst's (1974) value of $R = 5.6$. This difference is accounted for by the following features of the present analysis: (1) use of ZAMS-fitted data as well as data for 12 stars with known spectral types, (2) use of the ZAMS value of M_V for Herbst 72c rather than the value of luminosity class V (this is the star of largest color excess), and (3) adoption of a luminosity class of III rather than V for Herbst 74 [based on the results of new unpublished observations by Herbst (1975)]. Herbst 74 was not used in the analysis, but with an assumed value of $M_V = -0.5 \pm 0.5$ [plotted as an error bar in Fig. 6(d)] it agrees with the present value of R.

In the analysis of NGC 6649 it was found necessary to add 0.15 to the values of $U-B$ tabulated by Talbert

TABLE II. Results.

Cluster	l	X	n	Sp. T.	$(\overline{B-V})_0$	ΔE_{B-V}	R	p.e.	Data source
NGC 129	120°.3	0.76	79	b5	−0.03	1.06	3.01	±0.07	3, 9
NGC 225	122.0	0.76	13	b8	+0.16	0.46	3.04	0.27	9
NGC 654	129.1	0.76	44	b1	−0.18	0.55	2.92	0.16	9, 22
Cr 463	127.4	0.76	13	b8.5	+0.02	0.29	3.21	0.25	27
NGC 744	132.4	0.76	22	b8.5	+0.03	0.43	3.17	0.20	9
Basel 10	134.2	0.75	14	b1.5	−0.16	0.77	3.23	0.33	18
IC 1805	134.7	0.76	79	o6	−0.21	0.85	3.01[a]	0.06	9, 10, 19
Cz 8	135.8	0.75	11	b2:	−0.12	0.38	2.94	0.64	18
King 4	136.0	0.75	25	b4	−0.08	0.53	3.22	0.29	18
NGC 1039	143.6	0.75	12	b8.5	+0.08	0.23	3.43	0.24	11
α Per	147.0	. . .	37	b7	+0.14	0.20	3.24	0.26	16
Pleiades	166.6	0.75	43	b9.5	+0.22	0.36	3.11	0.15	12
NGC 1502	143.7	0.75	25	b0.5	−0.12	0.71	3.24	0.10	9
NGC 1528	152.0	0.75	42	b8	+0.22	0.50	3.15	0.13	9
NGC 1545	153.4	0.75	16	b8	+0.15	0.18	3.01	0.36	9
NGC 1647	180.4	0.77	16	b7	+0.24	0.30	2.86	0.30	9
NGC 1893	173.6	0.77	37	b0	−0.20	1.12	3.30	0.10	9
NGC 1907	172.6	0.77	30	b2	+0.09	0.52	3.26	0.18	9
NGC 1912	172.3	0.77	27	b9	+0.11	0.38	3.08	0.18	9
CV Mon	208.6	0.77	11	b7	+0.09	0.41	3.09	0.34	2
NGC 2264	202.9	0.77	13	b0.5	−0.15	0.45	3.20	0.17	29
NGC 2323	221.7	0.77	44	b8.5	+0.10	0.47	2.85	0.11	9
NGC 2345	226.6	0.76	21	b5	−0.12	0.38	3.09	0.17	17
Tr 9	243.1	0.76	10	b5	−0.11	0.42	2.75	0.26	28
Mel 101	289.9	. . .	12	b5	−0.12	0.38	3.06	0.25	4
Lyngå 2	313.8	0.72	20	b7	+0.02	0.72	3.16	0.10	13
NGC 5617	314.7	0.72	41	b6	−0.07	0.63	3.07	0.11	13
Hogg 17	314.9	0.73	15	b5	−0.07	0.46	3.03	0.22	13
NGC 6193	336.7	0.76	23	b1	−0.23	0.57	2.93	0.19	7, 18, 32
NGC 6322	345.3	0.78	35	b0.5	−0.02	0.57	3.33	0.11	14, 20
NGC 6611	17.0	0.74	87	o6	−0.12	1.12	3.04[a]	0.07	8, 31
NGC 6649	21.6	0.74	22	b3	−0.09	0.42	3.03	0.22	15, 26
NGC 6664	24.0	0.74	13	b3	−0.09	0.54	2.80	0.29	1, 23
Tr 35	28.3	0.74	28	b2:	−0.13	1.14	2.92	0.10	33
NGC 6709	42.2	0.74	20	b8	+0.17	0.28	3.36	0.18	9
NGC 6755	38.6	0.74	29	b0.5	−0.14	0.44	3.18	0.13	9
NGC 6802	55.3	0.74	25	b5	+0.15	0.60	3.00	0.12	9
NGC 6830	60.1	0.72	30	b5	−0.10	0.68	3.11	0.16	9
NGC 6834	65.7	0.75	63	b1	−0.11	0.57	2.96	0.13	9
NGC 6910	78.7	0.83	26	b0	−0.16	0.74	3.12	0.12	9
NGC 6913	76.9	0.83	18	b2	−0.15	0.50	3.11	0.24	9, 21
NGC 7062	89.9	0.81	13	a0	+0.22	0.43	2.81	0.21	9
NGC 7067	91.2	0.81	13	b1.5	−0.22	0.40	3.08	0.15	9
Tr 37	99.3	0.78	10	b0	−0.25	0.23	2.91	0.21	5, 25
NGC 7128	97.4	0.80	12	b2	−0.20	0.30	2.96	0.24	9
IC 5146	94.4	0.79	11	b1:	−0.08	0.83	2.89	0.20	30
NGC 7261	104.0	0.77	12	b7	+0.13	0.39	3.30	0.24	9
Basel 2	110.6	0.75	17	b3	+0.17	0.60	3.12	0.13	6
NGC 7510	111.0	0.75	17	o9	−0.24	0.46	3.34	0.15	9
NGC 7654	112.8	0.75	32	b5.5	−0.08	0.32	3.03	0.15	9, 22
NGC 7790	116.6	0.74	13	b5	−0.13	0.25	3.09	0.57	24

[a] Some additional evidence for existence of isolated region of anomalous *R* in same cluster.

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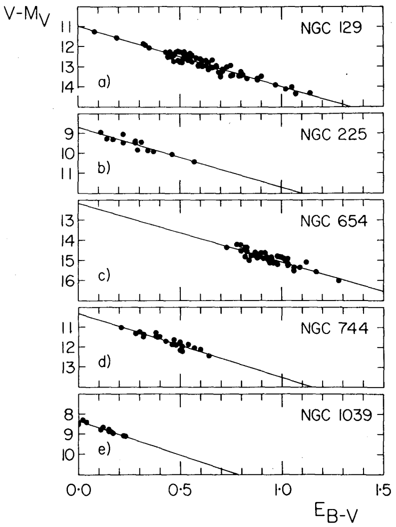

FIG. 3. Results of variable-extinction analyses for (a) NGC 129 (R = 3.0), (b) NGC 225 (R = 3.0), (c) NGC 654 (R = 2.9), (d) NGC 744 (R = 3.2), (e) NGC 1039 (R = 3.4).

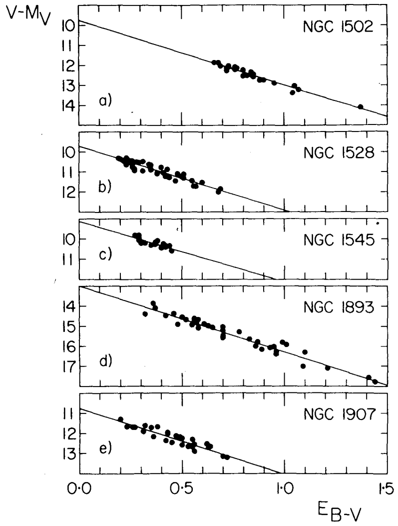

FIG. 4. Results of variable-extinction analyses for (a) NGC 1502 (R = 3.2), (b) NGC 1528 (R = 3.2), (c) NGC 1545 (R = 3.0), (d) NGC 1893 (R = 3.3), (e) NGC 1907 (R = 3.3).

(1975) in order to put them on the system defined by the photoelectric observations of Madore and van den Bergh (1975). This particular difference between the electrographic and photoelectric photometry is deserving of further study.

The ten stars used to derive $R = 2.9$ for the cluster Tr 37 are all objects which have been classified as luminosity class V by Garrison (Garrison and Kormendy 1975). The resultant value of R is remarkably free from effects due to scatter in the photometry despite the problems encountered from fitting stars with a small spread in color excess to the extreme blue end of the ZAMS [see discussion by Turner (1976a)]. This is an indication of the excellent quality of the observational data for this cluster. On the other hand, the large scatter in the data points for Basel 10, Cz 8, and King 4 reflects a rather large scatter in the photometry for these clusters. Only photographic observations (Moffat and Vogt 1973) are available here for cluster stars.

The unusual spread in the values of color excess for stars in IC 5146 exhibits the patchy nature of the extinction in this cluster. Membership for all but two of the plotted stars is confirmed by their association with the nebulosity around the cluster. The remaining two stars lie projected against the prominent dark cloud which is associated with this cluster.

Only the lower-envelope data are plotted for each cluster in Figs. 3–11. As can be seen from Figs. 1 and 2 [as well as from Fig. 3 of Turner (1976a)], the choice of stars defining the lower envelope involves a certain amount of judgment on the part of the person performing the analysis. This is generally only of importance, however, for clusters with small amounts of differential reddening. As evidenced by the apparent distribution of cluster R values with spread in color excess [Fig. 12(a)], no significant amount of bias appears to have been introduced into the analyses from this source. The same conclusion also applies to the use of linear reddening lines.

The distribution of R values with the average intrinsic color of the analyzed stars [Fig. 12(b)] does suggest the existence of a weak correlation. The apparent direction of this correlation, namely that R increases with increasing color index, is in the same sense as indicated by theoretical considerations of the expected changes in the effective wavelengths of the *UBV* filters due to differing stellar energy distributions. However, the observational

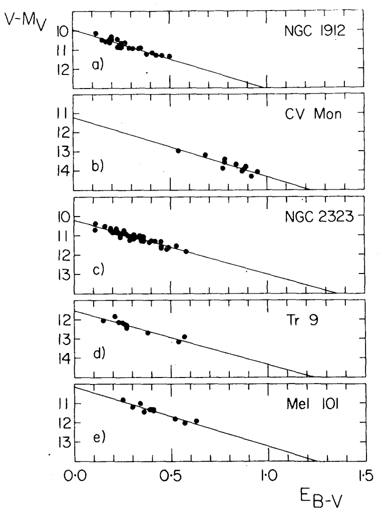

FIG. 5. Results of variable-extinction analyses for (a) NGC 1912 (R = 3.1), (b) CV Mon cluster (R = 3.1), (c) NGC 2323 (R = 2.8), (d) Tr 9 (R = 2.8), (e) Mel 101 (R = 3.1).

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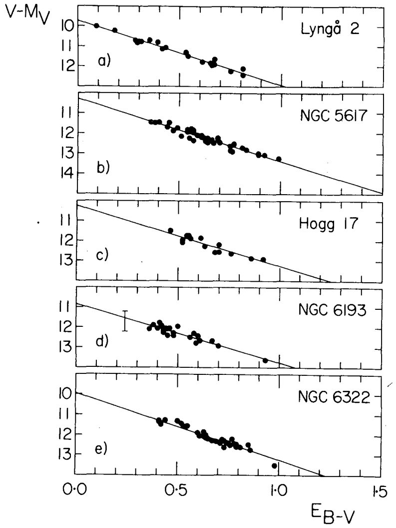

FIG. 6. Results of variable-extinction analyses for (a) Lyngå 2 ($R = 3.2$), (b) NGC 5617 ($R = 3.1$), (c) Hogg 17 ($R = 3.0$), (d) NGC 6193 ($R = 2.9$), (e) NGC 6322 ($R = 3.3$).

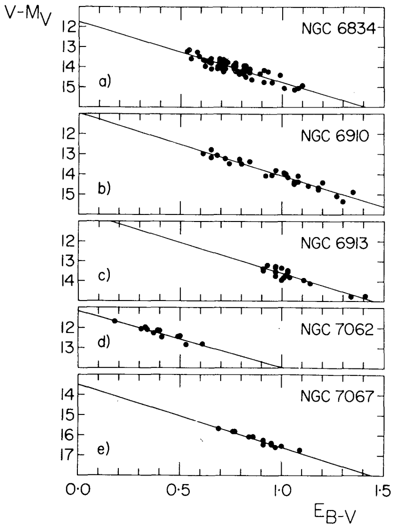

FIG. 8 Results of variable-extinction analyses for (a) NGC 6834 ($R = 3.0$), (b) NGC 6910 ($R = 3.1$), (c) NGC 6913 ($R = 3.1$), (d) NGC 7062 ($R = 2.8$), (e) NGC 7067 ($R = 3.1$).

data alone are certainly not adequate for accurately defining this relation.

A plot of R versus galactic longitude [Fig. 12(c)] may also show evidence for a weak correlation, but this is masked by the scatter in the data points. This scatter can be reduced significantly by averaging the data over selected intervals of galactic longitude and ignoring two clusters which lie outside the galactic plane (Table III). This analysis indicates that R may be slightly larger than average in the region of the galactic anticenter, while on the other hand it is smallest for those directions where the line of sight apparently falls along a spiral arm (Vulpecula–Cygnus and Puppis–Vela–Carina). These results agree qualitatively with those predicted from studies of interstellar polarization (e.g., Serkowski *et al.* 1975).

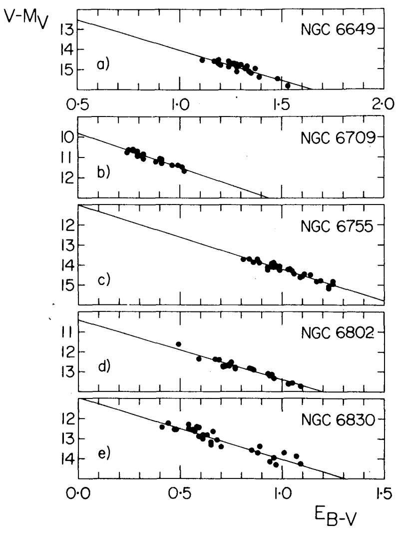

FIG. 7. Results of variable-extinction analyses for (a) NGC 6649 ($R = 3.0$), (b) NGC 6709 ($R = 3.4$), (c) NGC 6755 ($R = 3.2$), (d) NGC 6802 ($R = 3.0$), (e) NGC 6830 ($R = 3.1$).

The weighted mean value of R for all 51 clusters is $\bar{R} = 3.08 \pm 0.02$ p.e. An unweighted average of the individual results leads to a similar estimate of $\bar{R} = 3.08 \pm 0.02$ m.e.

The present result compares well with similar weighted means derived by other authors using different methods, a summary of which is given in Table IV. The mean value of Gebel's (1968) results for 17 H II regions

TABLE III. Regional averages of R.

Region	l	Clusters	$\bar{R}$	p.e.
Anticenter	140°–220°	10	3.23	±0.05
Center	320°– 40°	7	3.07	0.04
Vul–Cyg	55°–100°	10	3.01	0.05
Cep–Cas	100°–140°	13	3.06	0.04
Pup–Vel–Car	220°–290°	4	2.92	0.08

TABLE IV. Determinations of R by various methods.

Method	R	s.e.	Reference
Kinematic (cepheids)	2.7	±1.0	Bell (1971)
Kinematic (clusters)	3.1	1.7	Bell and Fitzgerald (1971)
Cluster diameters	3.15	0.20	Harris (1973)
H II regions	3.04	0.31	Gebel (1968)
Color difference	3.14	0.10	Schultz and Wiemer (1975)
Dark clouds	3.01	0.08	Schalén (1975)
Variable extinction (R associations)	3.31	0.19	Herbst (1975)
Variable extinction (OB associations)	3.05	0.07	Fernie and Marlborough (1963)
Variable extinction (OB associations)	3.02	0.02	Isobe (1968)
Variable extinction (clusters)	3.08	0.03	This paper

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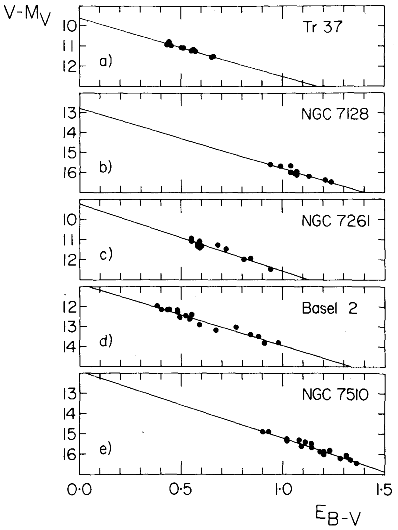

FIG. 9. Results of variable-extinction analyses for (a) Tr 37 (R = 2.9), (b) NGC 7128 (R = 3.0), (c) NGC 7261 (R = 3.3), (d) Basel 2 (R = 3.1), (e) NGC 7510 (R = 3.3).

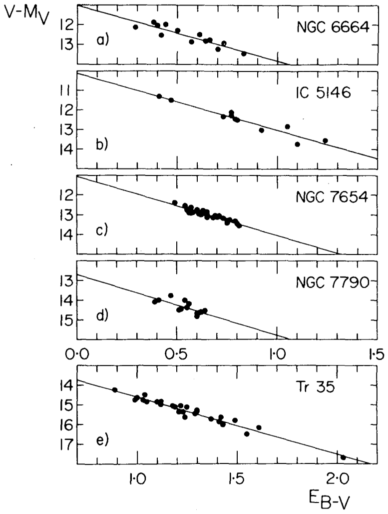

FIG. 11. Results of variable-extinction analyses for (a) NGC 6664 (R = 2.8), (b) IC 5146 (R = 2.9), (c) NGC 7654 (R = 3.0), (d) NGC 7790 (R = 3.1), (e) Tr 35 (R = 2.9).

has been listed here, and Schalén's (1975) result for dark clouds is that based on his analysis using a variable reddening law. Similarly, the quoted result from Fernie and Marlborough (1963) is from a weighted mean of their results for individual associations.

IV. DISCUSSION

The present results give additional support to the conclusions reached by Turner (1976) regarding the use of the variable-extinction method. When properly applied this method gives quite consistent estimates of R in galactic clusters, even when the spread in color excess for member stars is small. The presence of variable extinction in many of the clusters studied in this paper is probably accounted for by patchiness in the foreground extinction. In several cases, however, the extinction is undoubtedly related to material associated with the cluster stars. There appears to be no distinct difference in the values of R for the two cases, although it should be mentioned that a few clusters where R was found to be significantly larger than 3 have not been discussed in this paper. Those clusters where isolated anomalies appear to exist will be discussed in detail in future papers.

The results of the present analyses lead to a mean value of R for the galactic plane which is on the order of 3.1. The existence of a larger-than-average value of R (3.2) for the region of the galactic anticenter and a smaller than average value (3.0) for Cygnus may be real, so that extinction corrections for reddened objects may depend on their direction in space. Further work in this

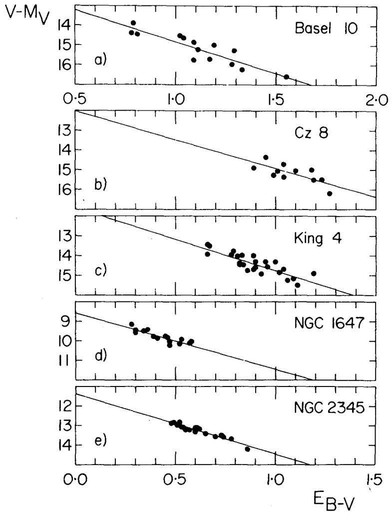

FIG. 10. Results of variable-extinction analyses for (a) Basel 10 (R = 3.2), (b) Cz 8 (R = 2.9), (c) King 4 (R = 3.2), (d) NGC 1647 (R = 2.9), (e) NGC 2345 (R = 3.1).

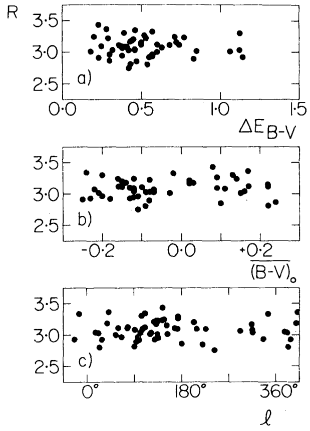

FIG. 12. The values of R from Table II plotted without regard for probable errors as functions of (a) total spread in color excess, ΔE_{B-V}, (b) average intrinsic color $(\overline{B-V})_0$, and (c) galactic longitude l.

area, particularly with regard to OB associations and southern hemisphere clusters, would clearly be of value for extending our knowledge of the value of *R* in the Galaxy.

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