1973, *Astron. Astrophys. Suppl.* **9**, 233-250.

PHOTOMETRIC STUDY OF THE OPEN CLUSTER NGC 2516

A. FEINSTEIN, H. G. MARRACO and I. MIRABEL
Observatorio Astronómico, Universidad Nacional de La Plata, Argentina

Received May 16, revised July 14, 1972

104 stars were observed in the *UBV* system, of which 28 and 23 were also in the *RI* and Hβ system, respectively. It was found that the dispersion of the observed color excesses is almost completely due to the intrinsic color dispersion rather than by that of the true excess. This was shown by means of an angular autocorrelation analysis fully explained in the appendix. A corrected modulus of $8^{\mathrm{m}}.00 \pm 0^{\mathrm{m}}.20$ and an age of 6×10^{7} years were obtained by treating the data with a mean color excess $\bar{E}_{B-V} = 0^{\mathrm{m}}.12$. All the peculiar stars observed by Abt and Morgan (1969) were found to be members. The relative position of the brightest star, which is of Be-type, in the color-magnitude and color-color diagrams is the same as in other clusters of the same age.

Key words: open cluster - *UBVRI* and Hβ photometry - color excess

1. INTRODUCTION

The open cluster NGC 2516 located in the Carina region, $\alpha = 7^{\mathrm{h}}58^{\mathrm{m}}$, $\delta = -60°40'$ (1950), has a large number of bright members and recently it became of interest because of the discovery of several peculiar stars among them. It was observed photoelectrically and photographically in the *PV* system by Cox (1955) who derived a distance of 400 ± 25 pc, from the study of 118 stars. Later Evans, Menzies, Stoy and Wayman (1961) provided $U_{c}BV$ photometry, MK spectral types and radial velocities for 15 stars brighter than $8^{\mathrm{m}}.5$ chosen among those observed by Cox. Abt and Morgan (1969) determined MK spectral types for 27 stars brighter than $9^{\mathrm{m}}.1$. Later on Abt, Clements, Doose and Harris (1969) measured rotational velocities for 30 stars brighter than $9^{\mathrm{m}}.4$, and obtained MK spectral types of 5 stars. Recently Dachs (1970) with a photoelectric *UBV* photometry of 70 stars found an interstellar reddening of $E_{B-V} = 0^{\mathrm{m}}.09$ and a distance of 375 ± 20 pcs. and finally more recently Abt and Levy (1972) searched for spectroscopic binaries in 16 stars brighter than $8^{\mathrm{m}}.5$ and got radial velocities for other 14 stars up to a limiting magnitude $9^{\mathrm{m}}.4$.

A discussion of part of the observations presented in the next section was given by one of us in a very preliminary version (Mirabel 1970).

Almost all the stars brighter than $9^{\mathrm{m}}.4$ have proper motions in the Cape Photographic Catalogue (Jackson and Stoy 1958) and in the Smithsonian Astrophysical Observatory Catalogue (1966). All the relevant data for the brightest stars are collected in Table 1, namely spectral types, rotational velocities, radial velocities and proper motions.

2. THE OBSERVATIONS

We have observed 104 stars in the *UBV* system, of which 28 and 23 are also in the *RI* and Hβ system, respectively. These observations were carried out with the 1 meter reflector of the European Southern Observatory at La Silla (Chile) in May 1969 and with the 80 cm reflector of the La Plata Observatory during January and February 1969, December 1970, and March and December 1971. In all cases standard one channel photometer was employed. The standard stars for the *UBVRI* were obtained from Johnson, Mitchell, Iriarte and Wisniewski (1966), and for Hβ from Crawford and Mander (1966), and Crawford, Barnes and Golson (1970). No use is made now of the *RI* measures in this paper, they are listed here for documentary purposes.

In addition to those stars observed by Cox (1955) we have also measured some bright stars in the neighbourhood of the cluster and some double stars in the cluster region. The results of the *UBV* photometry are listed in Table 2, those of the *RI* and Hβ photometry in Table 3.

We have taken from Wayman (1962) the *UBV* photometry for the quadruple star CPD −60° 944. The following identifications were made: CPD −60° 944c = Cox 112, CPD −60° 944d = Cox 104. For these stars we have adopted Wayman's values and they were added to Table 2 to make a total of 106 stars. Cox did not measure stars CPD −60° 944a and b. For these stars Wayman's values were averaged with our measures giving twice more weight to his measures than to ours. It should be noted than neither these stars nor HD 66066 and HD 66167 are shown in the numbered identification chart of the cluster in Cox's article. These stars were omitted there because of duplicity.

The internal root mean square error was computed for the stars with several observations. The stars were grouped in brighter and fainter than $V = 10^{\text{m}}$. The final results for the root mean square error on one observation in each color follow:

$$\begin{array}{lllll} V < 10^{\text{m}} & \varepsilon_V = \pm\,\overset{\text{m}}{.}030 & \varepsilon_{B-V} = \pm\,\overset{\text{m}}{.}022 & \varepsilon_{U-B} = \pm\,\overset{\text{m}}{.}025, & n = 15 \\ V > 10^{\text{m}} & \varepsilon_V = \pm\,\overset{\text{m}}{.}039 & \varepsilon_{B-V} = \pm\,\overset{\text{m}}{.}027 & \varepsilon_{U-B} = \pm\,\overset{\text{m}}{.}055, & n = 3 \end{array}$$

3. COMPARISON WITH OTHER OBSERVATIONS

We have compared our observations with those of other observers. The reproduction of our *UBV* system in terms of each observed system is given in Table 4 together with the number of stars in common and the unit weight error of the regression.

All the stars with residues greater than $0\overset{\text{m}}{.}07$ were eliminated from the regression. In the case of Cox's measures we employed only those stars with more than one photoelectric observation in each system.

The regression obtained in this way with the $P-V$ color of Cox compares well with that obtained by Eggen (1955):

$$\begin{array}{rll} B-V = & 0\overset{\text{m}}{.}120 & +\,0\overset{\text{m}}{.}964\,(P-V) \\ & \pm\,\overset{\text{m}}{.}001 & \pm\;\overset{\text{m}}{.}012 \text{ (p.e.)} \end{array}$$

Using the regression relations obtained above we transformed the remaining photoelectric and all photographic observations of Cox's paper to our *BV* system and compared it with our observations. It was found that stars with Cox's numbers 15 and 41 are variable in this 15 year interval. The V magnitudes of these stars, together with that of the previously known variable Cox A = HD 66194 (Feinstein 1968) transformed to our system are shown in Table 5.

A remarkable effect was found: namely that the magnitude and color scales of Cox's photographic measures are wrong for stars fainter than $11\overset{\text{m}}{.}5$ and redder than $B-V = 0\overset{\text{m}}{.}5$. This may be seen clearly in Figures 1 and 2. The differences are ours minus Cox's (transformed) values. This effect was foreseen by Cox but to a lesser extent. It fully accounts for the deviation of his points from the main sequence in his Figure 4.

4. ANALYSIS OF THE REDDENING

We obtained color excesses for the brighter stars (i.e. those of Table 1) in two ways. Firstly by using the intrinsic color for the corresponding spectral types, secondly, by running back the star to the intrinsic two color relation in the $(B-V,\ U-B)$ diagram (Feinstein and Marraco 1971). The computed excesses are tabulated in the last two columns of Table 2. These calculations were made with the intrinsic colors given by FitzGerald (1970) and taking the ratio of color excesses $\varkappa = 0.69$.

The mean values and the dispersions of these excesses are:

$$\begin{array}{lll} \text{Spectral types: } \bar{E}_{B-V} = 0\overset{\text{m}}{.}122, & \sigma_E = 0\overset{\text{m}}{.}028, & n = 35 \\ \text{Photometry: } \bar{E}_{B-V} = 0\overset{\text{m}}{.}112, & \sigma_E = 0\overset{\text{m}}{.}035, & n = 22 \end{array}$$

If we exclude the stars more likely to be non-members on the basis of their position in the sky, and/or their location in the color magnitude and color color diagrams: HD 66341, HD 65663, CPD −60° 944a and b, HD 66167 and Cox 9, we obtain for the photometric data:

$$\text{Photometry: } \bar{E}_{B-V} = 0\overset{m}{.}119, \quad \sigma_E = 0\overset{m}{.}021 \;, \quad n = 29$$

In order to decide whether in our further study we have to apply the individual color excesses of the stars, or to treat their data with the mean color excess, an angular autocorrelation analysis of the photometric excesses (see Appendix) was performed.

With 42 stars earlier than A0 the results were:

$$\bar{E}_{B-V} = 0\overset{m}{.}118, \quad \sigma_E = 0\overset{m}{.}029$$

This is the *observed* dispersion. The analysis allows us to say that the *true* dispersion is:

$$\sigma_E = 0\overset{m}{.}0095$$

and the dispersion due to causes other than reddening (that is observational errors, duplicity, rotation, chemical composition, etc.) is:

$$\sigma_\Delta = 0^{m}027$$

We can separate further the effect of the observational errors by means of the above quoted mean square internal error of our photometry. Taking the mean for the number of observations of each star as 4, it results for stars brighter than $V = 10^m$ an error:

$$\varepsilon_{B-V} = \frac{\pm 0\overset{m}{.}022}{\sqrt{4}} = \pm 0\overset{m}{.}011 \;, \quad \varepsilon_{U-B} = \frac{\pm 0\overset{m}{.}025}{\sqrt{4}} = \pm 0\overset{m}{.}0125$$

By equation (12) of Appendix we have a contribution to σ_Δ due to errors in the measurements:

$$\sigma_\delta = \pm 0\overset{m}{.}014$$

Then we have for causes like duplicity, rotation and inequalities in chemical composition, a dispersion of

$$\sigma = \pm 0\overset{m}{.}023$$

We concluded that in this cluster the dispersion caused by the true reddening is much smaller than that produced by other causes. It was decided that the mean excess should be used through the remaining reduction.

As comparison, the same angular autocorrelation analysis was made by Marraco (1973) for two other clusters: NGC 4609 (Feinstein and Marraco 1971a) and Trumpler 16 (Feinstein 1973). These results are shown in Table 6.

It can be seen that it is more reasonable to use individual excesses in the other two clusters since there the true reddening dispersion is larger than the dispersion due to other causes.

5. CLUSTER DISTANCE MODULUS, AGE AND MEMBERSHIP

For all the computations in this section a uniform color excess $E_{B-V} = 0\overset{m}{.}12$ was employed. The adopted values of the ratio of color excesses, and of total to selective absorption were respectively $\varkappa = 0.69$ and $R = 3$.

In Figures 3, 4 and 5 are plotted the color-color and both color magnitude arrays. In order to establish the distance modulus we discarded as obvious non-member stars those with Cox numbers 25, 27, 49, 50, 52, 64, 90 and 102, because of their position in the color-magnitude diagrams. The intrinsic color relation for dwarf stars corrected for the reddening was drawn in the two color diagram (Figure 3) and then labelled with absolute magnitudes taken from the ZAMS at the corresponding color. We employed the intrinsic colors of FitzGerald (1970) and the ZAMS absolute magnitudes from Johnson (1963). In this way we could obtain an absolute magnitude for each star by interpolating it between the two adjacent markings in the color-color array.

Finally we employed the method of Johnson (1960) for obtaining the distance modulus, but modified in two aspects. Firstly we assumed uniform excess instead of individual as was explicitly discussed in the preceding section. Secondly there was used a mean evolution curve different from that obtained by Johnson: it is that given by Lindoff (1968) and shown in Figure 4 of his paper. Figure 6 shows the final fitting both in distance modulus (vertical) and in age (horizontal), in the corrected distance modulus versus the corrected apparent magnitude diagram. Allowance was done for duplicity amongst the fainter members: that is the vertical fit was made taking into account that double stars may be up to $0\overset{m}{.}75$ brighter than a single star of the same colors. Then, double stars may have distance modulus smaller by the same amount.

The resulting corrected modulus and its estimated error is $V_o - M_v = 8\overset{m}{.}00 \pm 0\overset{m}{.}20$ meaning a distance of 400 ± 35 pc. The reason that this distance is slightly larger than that obtained by Dachs (1970) is because we have allowed for duplicity.

As a check of our photometric modulus and with the purpose of detecting non-members amongst the brighter stars we compared the absolute magnitude obtained with our uncorrected photometric modulus:

$$M_v = V - 8\overset{m}{.}36$$

against those obtained by means of our Hβ photometry and the MK spectral types of Abt and Morgan (1969). This can be seen in Figure 7. We used Fernie (1965) calibration for $M_v(\beta)$ and that of Schmidt-Kaler (1965) for M_v(MK).

If we allow a $0\overset{m}{.}75$ band for duplicity and additional $0\overset{m}{.}5$ and $0\overset{m}{.}6$ standard deviations for the $M_v(\beta)$ versus M_v, and M_v(MK) versus M_v relations, respectively, we can conclude that probably, only the stars HD 66066, Cox 37 and 48 are non-members on the basis of their Hβ photometry, and Cox 5 on the basis of its spectral type.

Thus, our distance modulus is confirmed by this method. Using the distance modulus obtained in this way, the upper margin of Figure 6 was labelled with absolute magnitudes and the position of the evolved part of the main sequence compared with the theoretical evolution deviation curves plotted in Figure 3 of Lindoff (1968). Thus we obtained an age of 6×10^7 years. This age is intermediate between those got by Dachs (1970): 5.5×10^7 years (= Pleiades) and by Lindoff (1968): 7×10^7 years.

A graph of proper motions is shown in Figure 8. A circle with radius $0\overset{''}{.}018$/year was drawn, which means about two standard deviations of all the proper motions. Outside this radius we have only the stars with Cox numbers 6, 9, 63 and HD 66066 and 66167, which could be considered non-members on the basis of their proper motions.

6. Ap, EMISSION AND SHELL STARS

After the inspection of Figures 3, 4 and 5 it is clear that the Ap stars are the bluest members of the cluster. This is more remarkable in the $U-B$ versus V diagram (Figure 5) in which they occupy the blue envelope of the main sequence. At the same time they are all nearly very close to the main sequence (not ZAMS) in Figure 6 suggesting no peculiarities in the absolute magnitudes and also low probability of being binaries. This agrees with current ideas about Ap stars as they appear at the same absolute magnitudes as normal stars (Jaschek and Jaschek 1962).

It is found that the star Cox 97 has colors that may put it in the domain of Am stars. It should be very valuable to decide spectroscopically about its metallicity because of the relative youngness of the cluster; see for instance Conti (1970) or Conti and van den Heuvel (1970).

The brightest blue star, HD 66194 (B2 Vne) occupies the same relative position in the two color diagram as the Be stars in the open clusters NGC 6025 (Feinstein 1971) and NGC 4609 (Feinstein and Marraco 1971a), where they are also the brightest. As was shown by Feinstein (1968) the emission B stars display ultraviolet excesses and therefore HD 66194 can be a member of NGC 2516 in spite of its position in the color magnitude arrays.

No peculiarity is found in the properties of the shell star Cox 41, except that its absolute magnitude obtained from the Hβ photometry is meaningless. The same conclusion can be drawn for the Be star Cox A (see Figure 7b).

APPENDIX

by H. G. Marraco and A. Feinstein

1. THE STRUCTURAL FUNCTION $\overline{(E-E_\varphi)^2}$

The angular autocorrelation analysis of the photometric excesses is done by means of the structural function $\overline{(E-E_\varphi)^2}$ as defined by Serkowski (1958) in section 1.3. Our procedure to obtain this function differs from Serkowski's in two aspects: a. we obtained the color excesses entirely photometrically, without any reference to spectral types (see last paragraph of this Appendix); b. the function was averaged by means of a smoothing procedure in a large computer instead of grouping the points over certain intervals of φ (Feinstein and Marraco 1971b).

2. OBSERVED AND TRUE EXCESS

We shall call the excesses obtained from the observed colors: observed excesses E'_{bv}. But the star may actually have reddened to the observed colors from any point along the reddening path as is shown in Figure 9. So there is an excess actually produced by the interstellar material that we may call true excess E_{bv}.

We define the quantity

$$\Delta_{bv} = E'_{bv} - E_{bv} \tag{1}$$

Taking a pair of stars we can write (dropping the subindex *bv*)

$$E'_i - E'_j = \Delta_i - \Delta_j + E_i - E_j \qquad \text{where } i, j = 1, 2, 3, \ldots;\ i \neq j \tag{2}$$

Then squaring and taking mean values

$$\overline{(E'_i - E'_j)^2} = \overline{\Delta_i^2} + \overline{\Delta_j^2} + \overline{2(E_i - E_j)\,\Delta_i} - \overline{2(E_i - E_j)\,\Delta_j} - \overline{2\Delta_i\Delta_j} + \overline{(E_i - E_j)^2}. \tag{3}$$

Now we recall that, by our definition (1), Δ and E are entirely independent variables which add up to form the observed excess E'. In addition $\overline{\Delta} = 0$ because when the intrinsic color relations were obtained the colors of the unreddened stars were simply averaged.

As stars *i* and *j* are statistically indistinguishable we put $E_i - E_j = E - E_\varphi$, and the same for the primed quantities, where φ is the angular separation between stars *i* and *j*, that is $\varphi = \varphi(i, j)$. Furthermore $\overline{\Delta_i^2} = \overline{\Delta_j^2} = \overline{\Delta^2}$; we then obtain

$$\overline{(E' - E'_\varphi)^2} = 2\overline{\Delta^2} + \overline{(E - E_\varphi)^2} \tag{4}$$

The observed dispersion of the color excesses can be expanded too

$$\sigma^2_{E'} = \overline{E'^2} - (\overline{E'})^2 = \overline{(\Delta + E)^2} - (\overline{\Delta + E})^2 = \overline{\Delta^2} + \overline{E^2} + 2\overline{\Delta E} - (\overline{\Delta})^2 - (\overline{E})^2 - 2\overline{\Delta}\,\overline{E} \tag{5}$$

With the same arguments used in obtaining (4) we conclude

$$\sigma^2_{E'} = \overline{\Delta^2} + \sigma^2_E \tag{6}$$

3. THE ANGULAR AUTOCORRELATION COEFFICIENT

Now we can make use of equation (24) of Serkowski's paper

$$\overline{(E - E_\varphi)^2} = 2\sigma^2_E[1 - r(\varphi)] \tag{7}$$

where $r(\varphi)$ is the angular autocorrelation coefficient of the interstellar material. If no reddening takes place in the cluster itself this coefficient must be equal to unit for the zero value of the argument. Then, it follows

$$\overline{(E - E_\varphi)^2} = 0 \quad \text{when} \quad \varphi = 0$$

This is natural as we are looking through the same interstellar material.

It is clear now that we can obtain the value of $\overline{\Delta^2}$ from a plot of $\overline{(E' - E'_\varphi)^2}$ versus φ, taking the value extrapolated to $\varphi = 0$ as shown in Figure 10.

Finally the values of $\overline{(E - E_\varphi)^2}$ and σ_E can be obtained from equations (4) and (6) and the autocorrelation coefficient $r(\varphi)$ can be computed from equation (7). The later can be used for statistical description of the interstellar material (Serkowski 1958).

4. THE INFLUENCE OF OBSERVATIONAL ERRORS AND OTHER EFFECTS

Now we assume that for early-type main sequence stars the following relations hold

$$(U-B)_o = \alpha(B-V)_o, \qquad \alpha = 3.69 \tag{8}$$

$$E(U-B) = \varkappa E(B-V), \qquad \varkappa = 0.69 \tag{9}$$

Then we can compute observed excesses for these stars

$$E'(B-V) = \frac{\alpha(B-V)' - (U-B)'}{\alpha - \varkappa} \tag{10}$$

Putting for each color

$$(B-V)' = (B-V) + \varepsilon_{(B-V)}; \quad (U-B)' = (U-B) + \varepsilon_{(U-B)} \tag{11}$$

Where again the primes stand for observed values, the unprimed being for true values and the ε is the observational error in each color (see Figure 9).
Then

$$\sigma_{\delta_{B-V}} = \frac{\alpha^2 \cdot [\varepsilon_{(B-V)}]^2 + [\varepsilon_{(U-B)}]^2}{(\alpha - \varkappa)^2} \tag{12}$$

A similar analysis can be made for separating effects due to other facts that can modify the colors. In this case the unprimed quantities should be the colors corrected for the effect.

ACKNOWLEDGEMENT

The facilities given by the European Southern Observatory (La Silla) are specially acknowledged. This work has been performed while Hugo G. Marraco had a fellowship of the Consejo Nacional de Investigaciones Cientificas y Técnicas, and Igor Mirabel a grant from the Asociación Argentina de Astronomia. It was also partially supported by a contract of A. Feinstein with the Consejo Nacional de Investigaciones.

REFERENCES

Abt, H. A., Clements, A. E., Doose, L. R. and Harris, D. H.: 1969, *Astron. J.* **74**, 1153.
Abt, H. A. and Levy S. G.: 1972, *Astrophys. J.* **172**, 355.
Abt, H. A. and Morgan, W. W.: 1969, *Astron. J.* **74**, 813.
Cox, A. N.: 1955, *Astrophys. J.* **121**, 628.
Conti, P. S.: 1970, *Publ. Astron. Soc. Pacific* **82**, 781.
Conti, P. S. and Heuvel, van den, E. P. J.: 1970, *Astron. Astrophys.* **9**, 466.
Crawford, D. L., Barnes, J. V. and Golson, J. C.: 1970, *Astron. J.* **75**, 624.
Crawford, D. L. and Mander, J.: 1966, *Astron. J.* **71**, 114.

Dachs, J.: 1970, *Astron. Astrophys.* **5**, 312.
Eggen, O. J.: 1955, *Astron. J.* **60**, 131.
Evans, D. S., Menzies, A., Stoy, R. H. and Wayman, P. A.: 1961, *Roy. Observ. Bull.* 48.
Feinstein, A.: 1968, *Z. Astrophys.* **68**, 29.
Feinstein, A.: 1971, *Publ. Astron. Soc. Pacific* **83**, 800.
Feinstein, A.: 1973, (in preparation).
Feinstein, A. and Marraco, H. G.: 1971a, *Publ. Astron. Soc. Pacific* **83**, 218.
Feinstein, A. and Marraco, H. G.: 1971b, *Bol. Asoc. Arg. Astronomia* **16**, 16.
Fernie, J. D.: 1965, *Astron. J.* **70**, 575.
FitzGerald, M. P.: 1970, *Astron. Astrophys.* **4**, 234.
Jackson, J. and Stoy, R. H.: 1958, Cape Photographic Catalogue, *Ann. Cape Obs.* **20**.
Jaschek, M. and Jaschek, C.: 1962, J. Sahade (ed.), Considerations on the Evolution of Peculiar and Metallic-Line Stars, in *Symposium on Stellar Evolution*, National University of La Plata, La Plata, p. 137.
Johnson, H. L.: 1960, *Lowell Obs. Bull.* **5**, 17.
Johnson, H. L.: 1963, K. Aa. Strand (ed.), Photometric Systems, in *Basic Astronomical Data*, Univ. of Chicago Press, Chicago, p. 204.
Johnson, H. L., Mitchell, R. I., Iriarte, B. and Wisniewski, W. Z.: 1966, *Commun. lunar planet. Lab.* **4** no. 63. 99.
Lindoff, U.: 1968, *Arkiv Astron.* **5**, 1.
Marraco, H. G.: 1973, (in preparation).
Mirabel, I.: 1970, *Bol. Asoc. Arg. Astronomia* **15**, 14.
Schmidt-Kaler, Th.: 1965, K. H. Hellwege and H. H. Voigt (eds.), in *Landolt-Börnstein* Groupe 6, Vol. 1, Astronomy and Astrophysics, Springer-Verlag, Berlin, p. 297.
Serkowski, K.: 1958, *Acta Astron.* **8**, 135.
Smithsonian Astrophysical Observatory Star Catalogue, Smithsonian Institution, Washington, D. C., 1966.
Wackerling, Ll. R.: 1970, *Mem. Roy. Astron. Soc.* **73**, 153.
Wayman, P. A.: 1962, *Roy. Observ. Bull.* 50.

A. Feinstein
H. G. Marraco

Observatorio Astronómico,
Paseo del Bosque,
La Plata, Argentina

I. Mirabel

Instituto Argentino de Radioastronomia
Casilla de Correo 5, Villa Elisa,
Pcia de Buenos Aires, Argentina

1973A&AS....9..233F

Table 1 Spectroscopic, radial velocity and proper motion data for the brightest stars of NGC 2516.

			Abt et al. 1969, 1969 and 1972.					Evans et al. 1961.		CPC		SAO	
HD	CPD	Cox	Sp.T.	Pec.	V sin i	ρ	Δρ?	Sp.T.	ρ	μ_α	μ_δ	μ_α	μ_δ
	−60°		MK		Km s^{-1}	Km s^{-1}		MK	Km s^{-1}	$''/10^3$ yr.		$''/10^3$ yr.	
66342	1018	110	M1II					M0II	22.2	4	8	3	9
65662	935		*					*		1	2	11	12
66194	1006	A	B2Vne		250	12.7	Cst?	B3en	22	0	21	−8	13
66341	(954)*					*			*	4	16	4	2
	980	a	K1III					K1III	21.6	1	1	8	20
65663	937		*					*		9	19	10	−1
66066*	988											5	−17
65950	967	B	B8.5IIIp	Mn	30	18.9	Cst.	B9III	25.0	4	8	7	5
	982	b	B9.5IV		280	16.4	Cst.	B9V	14	−4	15	−2	12
65987	976	15	B9.5IVp	Si	15	7.6	Var?	A0p	23	−1	14	−3	5
65869	953	10	B8.5V		80	21.2	Cst.	B9V	20	3	5	−8	6
66137	1003	19	B9V		90	15.6	Var?	A0V	15	−6	10	−4	7
	947	13	B8V		260	24.6	Var?	B8V	17	3	−2	5	−5
	985	37	B8.5V		300	14.1	Cst.	B8V	21				
66656	1033	29	A0V		10	1.4:	SB1	A2V	14	−7	10	−4	7
65949	966	91	B9IVp	Hg	20	29.1:	SB1			−3	0	−1	−3
66259	1012	20	B9.5IV	Hg?	40	27.7:	SB1	A0V	30	−1	6	−12	9
66409	1022	23	B8.5IV	Mn?	40:	22.1	Cst.	B9V	24	7	4	10	1
	979	83	B8.5V		280	14.4:	SB1			14	9	16	6
	945	5	B8.5IV		50	22.4	Cst?	B8V	18				
	990	d	B9V		200	−1.9:	SB1						
	969	11	B9.5V		220	12.3:	SB1	A0Vn	18				
	993	48	B8.5IV-V		80	29				−10	12	−8	9
65931	960	39	B9V		80	50				0	24	2	21
	961	2	A0IV-V		40	33							
66167*	1005									−11	−14	−9	−17
65691	939	6	B8.5V		265	26				21	3	24	0
	978	c	A0p	Si	10	21.1							
	975	1	A0V		190	18							
	968	41	[B9p]	Shell	240	20							
66295	1015	26	A0p	Si	15	35				12	2	15	−1
65896	955	12	(A0V)		50	44				1	−4	3	−7
66442	1023	63	A2V		40	7				5	−19	8	−22
	952	9	(B9V)		300	23				15	23	17	20
	973	43	(A1V)		195	39							
	979	36	(A1V)		230	34				14	9	16	6
	1001	33								2	−1	4	−4
	964	14	(A0V)		255	49							

NOTES TO TABLE 1

HD 65662, K4 III quoted by Dachs (1970).

HD 66341, belongs to CPD zone −59°; ρ = 22.7 km s^{-1} from the General Catalogue of Radial Velocities.

HD 65663, emission star = Henize 103, B9, Wackerling (1970).

HD 66066, double star = HJ 4031, $\Delta m = 0.9$, sep. = 5″.5.

HD 66167, double star = I 1104, $\Delta m = 0.1$, sep. = 8″.5.

Table 2 *UBV* measures of NGC 2516

STAR	V	$B-V$	$U-B$	n	$(E_{B-V})_{\mathrm{Sp.}}$	$(E_{B-V})_{\mathrm{Ph.}}$	STAR	V	$B-V$	$U-B$	n	$(E_{B-V})_{\mathrm{Sp.}}$	$(E_{B-V})_{\mathrm{Ph.}}$
110	5.18	1.77	1.88	4			25	9.85	.56	.16	2		
65662	5.69	1.55	1.83	2			45	9.86	.19	.19	3		
A	5.82	–.08	–.81	8			65	9.86	.09	.06	1		0.10
66341	6.33	–.05	–.40	1		0.08	40	9.87	.22	.15	2		
a	6.69	1.28	1.20	4			112*	9.84	.27	.21	2		
65663*	6.77	.01	–.23	1		0.10	28	9.94	.16	.13	2		
66066*	6.82	0.00	–.26	1		0.10	7	9.95	.17	.16	3		
B	6.86	0.00	–.33	4		0.12	64	10.01	.40	.03	2		
b	7.21	.06	–.08	27	0.10	0.11	66	10.11	.21	.16	1		
15	7.59	–.04	–.41	2		0.10	57	10.15	.15	.18	2		
10	7.72	.03	–.19	5	0.12	0.11	101	10.16	.22	.14	1		
19	7.80	.06	–.11	6	0.13	0.12	86	10.22	.19	.18	1		
13	8.03	–.02	–.34	2	0.15	0.10	52	10.23	.41	.07	2		
37	8.19	.03	–.19	3	0.12	0.12	30	10.29	.19	.17	1		
29	8.26	.05	.01	2	0.06	0.06	34	10.33	.19	.18	1		
–60° 944a*	8.35	.03	–.34	2		0.16	46	10.36	.38	.11	3		
91	8.35	–.02	–.35	3		0.10	31	10.39	.37	.09	1		
20	8.37	.05	–.15	4	0.09	0.12	27	10.43	.61	–.06	3		
23	8.37	.01	–.32	3	0.10	0.13	35	10.46	.25	.19	2		
83	8.38	.05	–.16	2	0.14	0.12	54	10.53	.27	—	1		
5	8.53	.08	–.24	4	0.16	0.18	60	10.54	.33	.16	2		
d	8.55	.07	–.16	5	0.14	0.15	42	10.57	.27	.22	5		
11	8.55	.07	–.03	3	0.11	0.10	84	10.63	.36	.18	1		
48	8.74	.01	–.21	3	0.10	0.09	51	10.73	.32	.17	2		
39	8.75	.09	–.16	2		0.18	21	10.76	.29	.11	1		
2	8.76	.08	–.08	4	0.10	0.13	4	10.79	.38	.18	1		
66167*	8.78	.10	.10	1		0.10	67	10.79	.32	.17	2		
–60° 944b*	8.85	.07	–.31	2		0.20	109	10.81	.29	.13	1		
6	8.89	.04	–.11	3	0.13	0.10	44	10.84	.34	.21	2		
c	8.92	.07	–.24	5		0.18	97	10.87	.32	.27	3		
1	8.96	.12	.11	4	0.13	0.12	55	10.97	.33	.11	1		
41	8.98	.05	–.06	8		0.10	62	11.00	.35	.12	1		
26	9.11	.06	–.18	4		0.14	104*	11.00	.54	.06	1		
12	9.16	.09	.11	1	0.10	0.08	93	11.09	.33	.17	2		
63	9.20	.11	.13	3	0.06	0.10	96	11.15	.40	.07	2		
9	9.27	.14	.01	4	0.21	0.18	108	11.15	.40	.10	1		
43	9.36	.09	.05	2	0.07	0.10	107	11.34	.51	.05	4		
36	9.37	.11	–.01	1	0.09	0.14	56	11.37	.40	.05	1		
33	9.40	.19	.17	1			61	11.38	1.09	.76	1		
14	9.42	.05	.01	2	0.06	0.07	111	11.40	.53	.08	1		
3	9.44	.10	–.02	2		0.14	102	11.41	.14	–.16	2		
38	9.46	.21	.12	1			90	11.53	.80	.12	2		
18	9.53	.13	.11	3		0.13	79	11.63	.52	.10	2		
22	9.58	.22	.16	1			95	11.74	.49	.16	4		
94	9.58	.11	.06	10		0.13	72	11.75	.50	—	1		
16	9.60	.15	.17	2			88	11.89	.52	.04	1		
58	9.61	.11	.01	2		0.15	82	11.98	.48	.13	2		
24	9.62	.10	.19	2		0.09	74	12.00	.47	.10	1		
47	9.65	.22	.17	3			85	12.00	.59	.06	2		
77	9.65	.11	.10	2		0.11	100	12.04	.54	–.03	2		
8	9.66	.13	.13	2		0.12	75	12.18	.61	—	1		
17	9.75	.20	.09	4			103	12.32	.70	–.08	1		
49	9.75	1.36	1.46	3			78	12.74	.65	—	1		

See notes Table 2 following page.

NOTES TO TABLE 2

HD 65663, emission star = Henize 103.
HD 66066, double star = HJ 4021, $\Delta m = 0.9$, sep. = 5″.5.
CPD −60° 944a, combined photometry with Wayman (1962).
HD 66167, double star = I 1104, $\Delta m = 0.1$, sep. = 8″.5.
CPD −60° 944b, combined photometry with Wayman (1962).
Cox 112 = CPD −60° 944c, *UBV* photometry is taken from Wayman (1962).
Cox 104 = CPD −60° 944d, *UBV* photometry is taken from Wayman (1962).

Table 3 RI and Hβ photometry of NGC 2516

Star	*R*	*R–I*	*n*	β	*n*
110	3.74	1.13	2		
65662	4.66	0.82	1		
A	5.78	–0.06	2	2.520	2
a	5.81	0.70	3		
66341				2.655	1
66066				2.755	1
B	6.80	–0.01	2	2.693	3
b	7.09	0.11	2	2.716	4
15	7.56	–0.03	1	2.723	2
10	7.63	0.08	2	2.73:	1
19	7.65	0.09	2	2.811	2
13	8.08	–0.04:	1		
37	8.15	0.05	1	2.703	2
29	8.22	0.06	1		
91	8.30	0.05	1	2.778	1
20	8.28	0.06	1		
23	8.31	0.09	1		
5	8.44	0.09	1	2.77:	1
d	8.37	0.26:	1	2.829	1
11	8.48	0.10	1	2.835	1
48	8.77	0.04:	1	2.73:	1
39	8.68	0.03	1		
2	8.73	0.02	1	2.909	1
66167				2.826	1
6	8.87	0.03	1	2.80:	1
c	8.78	0.10	1	2.809	1
1	8.85	0.19	1	2.821	1
41	8.89	0.06	1	2.655	1
26	9.11	0.03	1		
12	9.09	0.14	1	2.979	1
63	9.09	0.08	1		
36				2.855	2
14				2.830	1

Table 4 Comparison of photometric systems
Our measures expresed in terms of other published values

Expression	Number of stars in common	Unit weight error	Ref.
V = V − 0.037 − 0.004(P–V) ±.000 ±.004(m.s.e.)	41	±.026	1
B–V = 0.942(P–V) + 0.140 ±.022 ±.000(m.s.e.)	44	±.016	
V = V − 0.010 + 0.015(B–V) ±.001 ±.005(m.s.e.)	15	±.019	2
B–V = 1.010(B–V) + 0.014 ±.003 ±.001(m.s.e.)	15	±.011	
V = V − 0.030 − 0.005(B–V) ±.001 ±.003(m.s.e.)	45	±.023	3
B–V = 0.988(B–V) + 0.016 ±.002 ±.000(m.s.e.)	48	±.013	
U–B = 1.002(U–B) + 0.010 ±.002 ±.001(m.s.e.)	48	±.030	

References: 1. Cox (1955), 2. Evans *et al.* (1961), 3. Dachs (1970).

Table 5 Stars with large differences in *V* magnitude

Cox number	Cox (1955)	Evans *et al.* (1961)	Dachs (1970)	This Paper
15	7.97	7.60	7.63	7.59
41	9.20	—	8.98	8.98
A	5.77	5.79	5.73	5.82

Table 6 Results from the angular autocorrelation analysis

Cluster	Mean Observed excess	Observed reddening dispersion	True reddening dispersion	Other causes dispersion	*n*
NGC 2516	$0^{\mathrm{m}}.118$	$0^{\mathrm{m}}.029$	$0^{\mathrm{m}}.0095$	$0^{\mathrm{m}}.027$	44
NGC 4609	0.357	0.042	0.033	0.026	33
Tr. 16	0.521	0.111	0.106	0.031	75

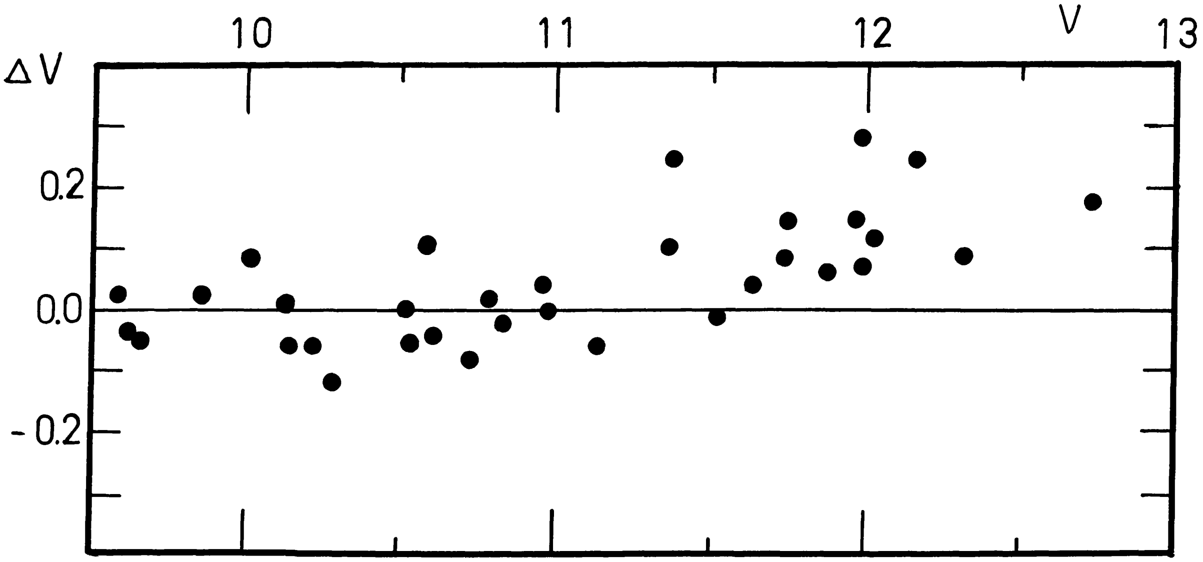


Figure 1 The difference between our V magnitude and Cox's transformed photographic V magnitude versus V. The differences ΔV are ours minus Cox's transformed.

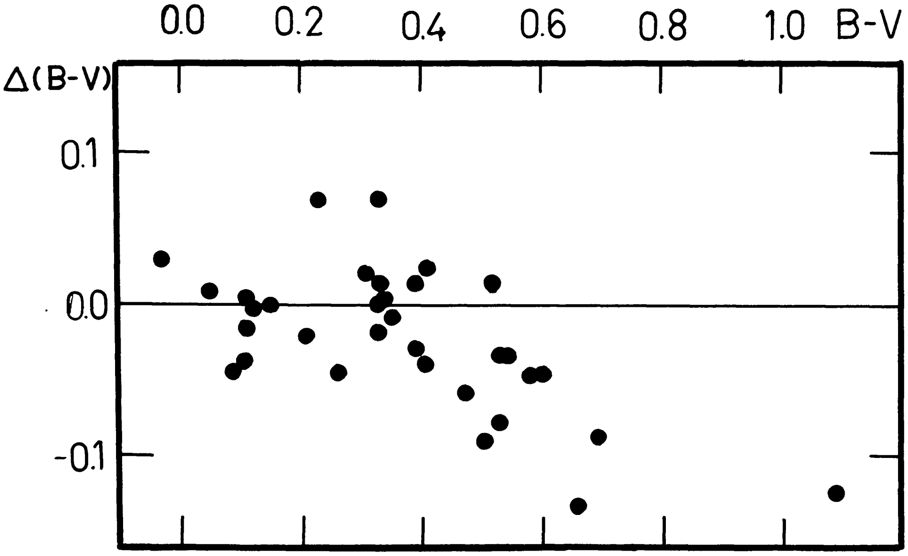


Figure 2 Comparison of Cox's photographic $P-V$ color transformed to $B-V$ with ours in function of $B-V$. The differences are in the same sense as in Figure 1.

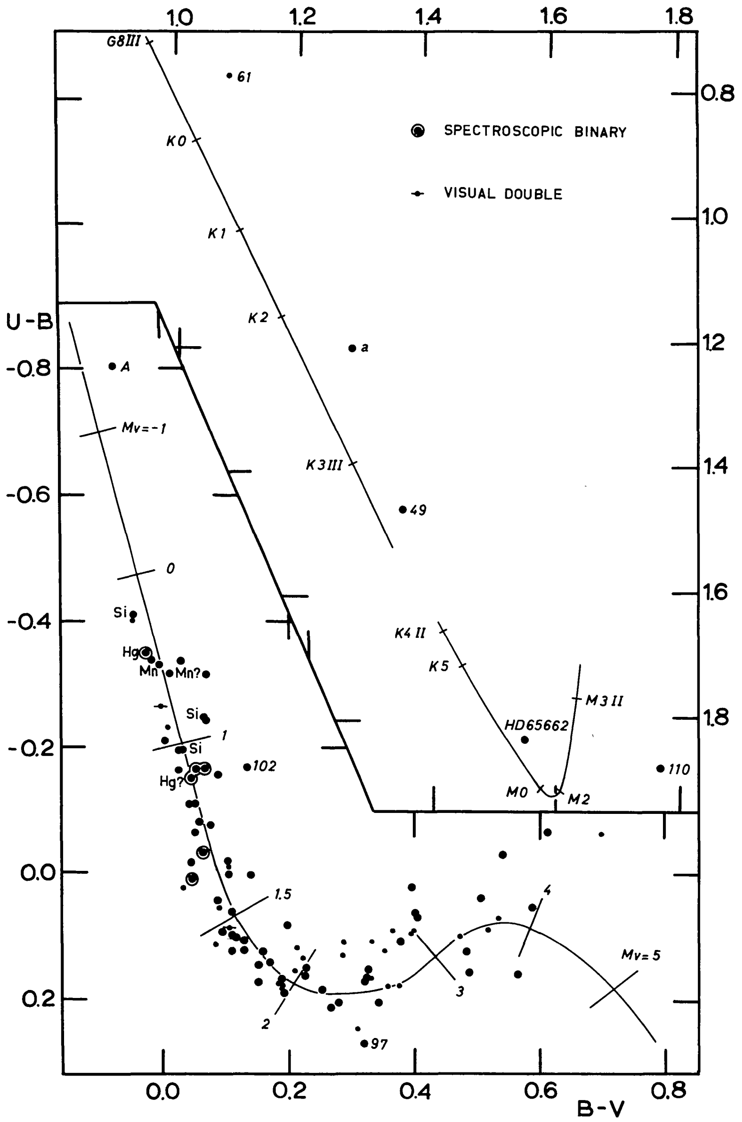
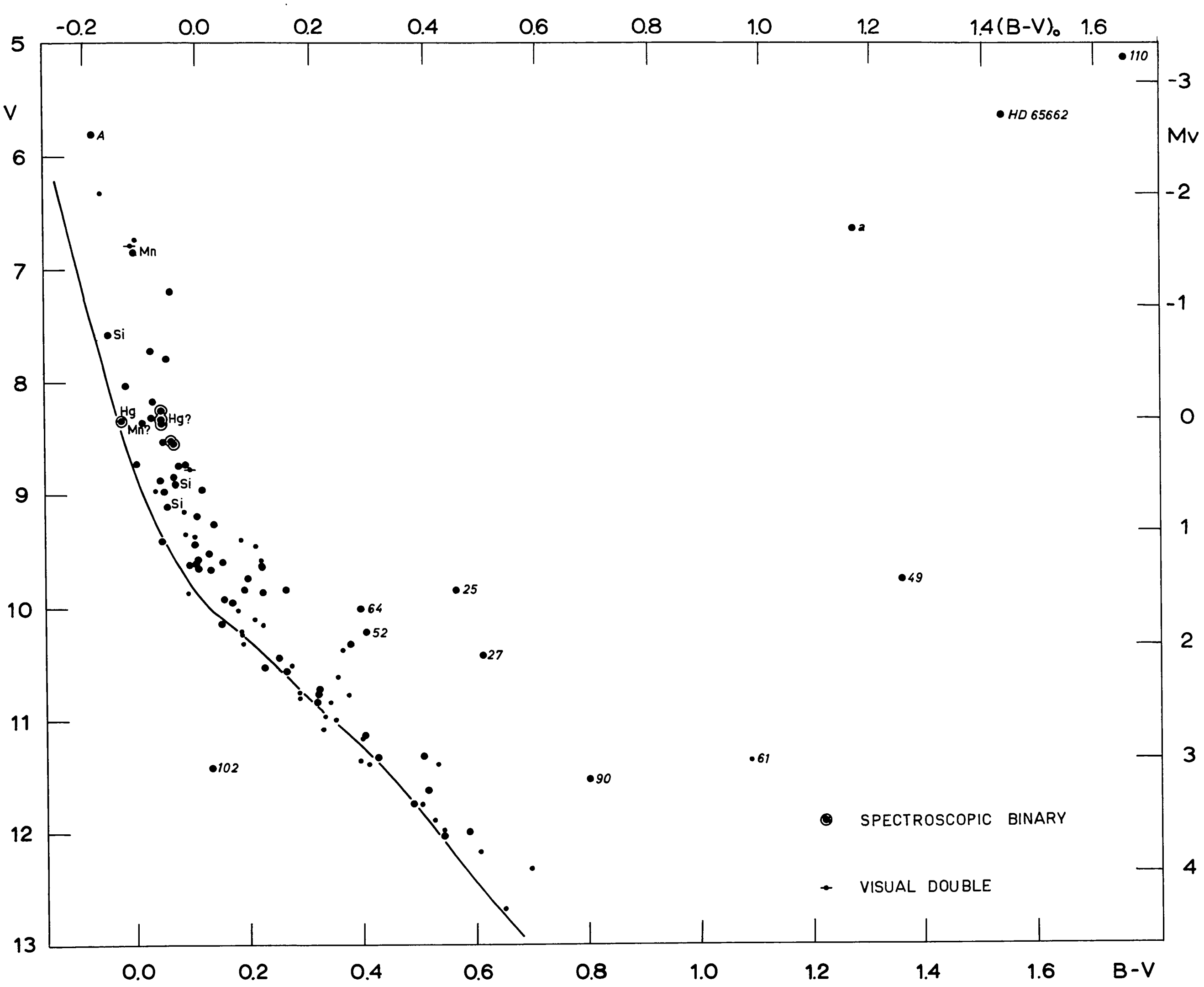


Figure 3 Color-color diagram for all the observed stars but Cox number 90. In the lower left is plotted the early part of the main sequence intrinsic color relation displaced with a computed excess $E_{B-V} = 0^{\mathrm{m}}.12$ and $E_{U-B} = 0^{\mathrm{m}}.08$. The sequence was labelled with absolute magnitudes corresponding to the ZAMS. Some of the stars in the range $0^{\mathrm{m}}.3 < B-V < 0^{\mathrm{m}}.7$ are non-members. In the upper right part are marked the intrinsic color relations for luminosity types II and III uncorrected for reddening. Through the whole figure small circles stand for stars observed once, large circles for those observed more than once. Some relevant stars have been identified.

Figure 4 Color-magnitude diagram for all the observed stars. The symbols have the same meaning as in Figure 3. The ZAMS has been drawn with a distance modulus $m-M = 8\overset{m}{.}36$ and an excess $E_{B-V} = 0\overset{m}{.}12$.



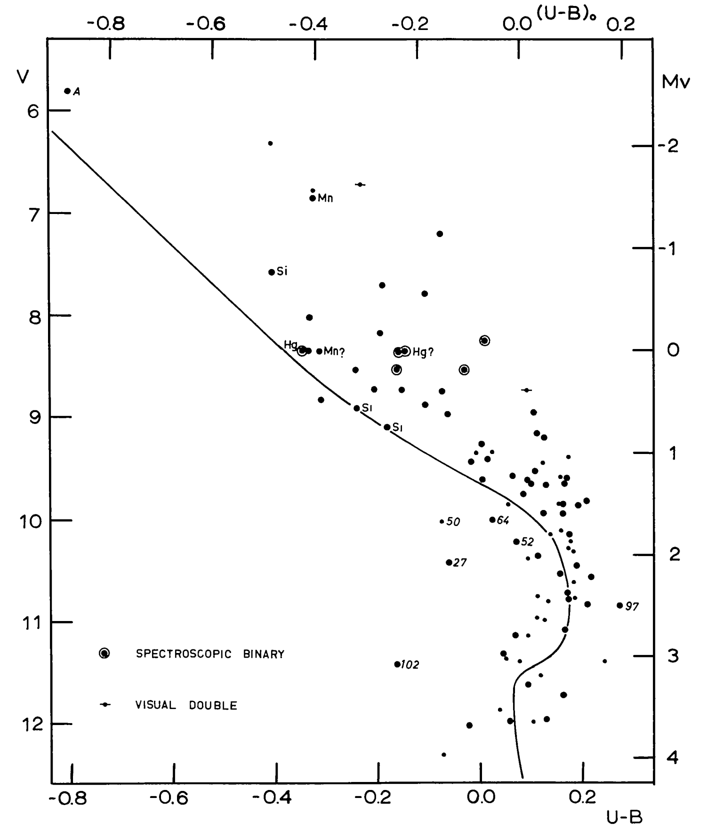


Figure 5 $U-B$ color-magnitude diagram for all but the reddest stars, that is only for those stars plotted in the lower left part of Figure 3. The symbols have the same meaning as in Figure 3. The ZAMS is plotted with a distance modulus $m-M = 8\overset{\mathrm{m}}{.}36$ and an excess $E_{U-B} = 0\overset{\mathrm{m}}{.}08$.

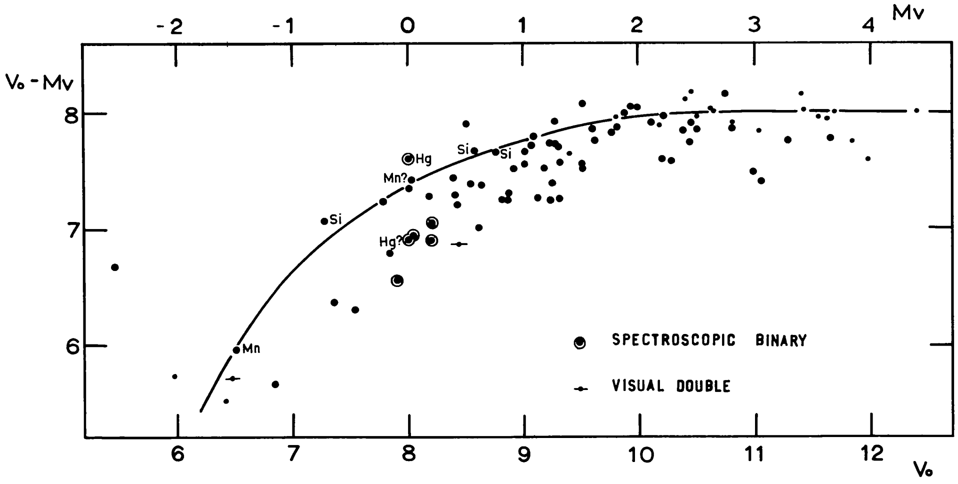


Figure 6 Corrected apparent magnitude versus corrected modulus diagram for the possible main sequence members. The symbols have the same meaning as in Figure 3. The line plotted is the mean evolution deviation curve (see text) fitted both in modulus and in magnitude. The upper margin is labelled in absolute magnitude with the corrected modulus $V_o - M_v = 8\overset{\mathrm{m}}{.}00$ obtained from the vertical fit.

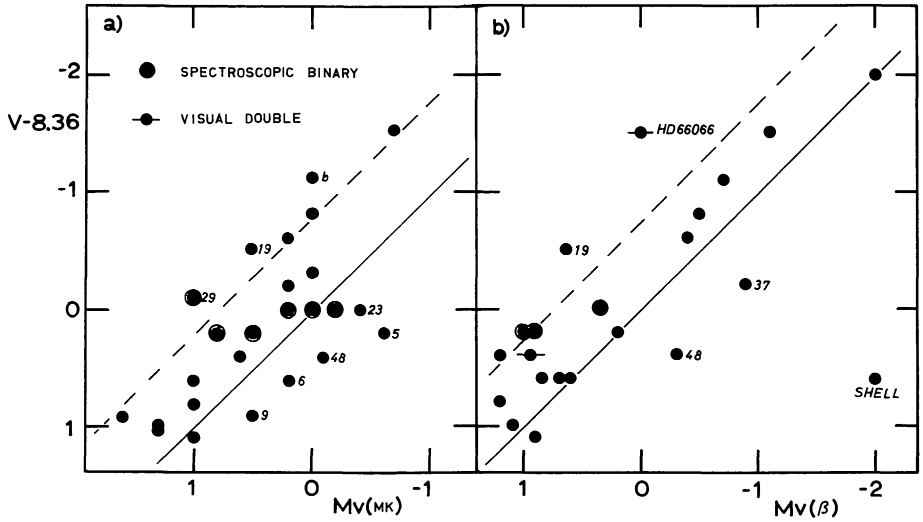


Figure 7 a) Comparison of absolute magnitude obtained from the cluster distance and from MK spectra. b) Comparison of absolute magnitude obtained from the cluster distance and from Hβ photometry. The dashed line which is $0^{m}\!.75$ above the one to one line relation is adopted as the limit to the position of double stars.

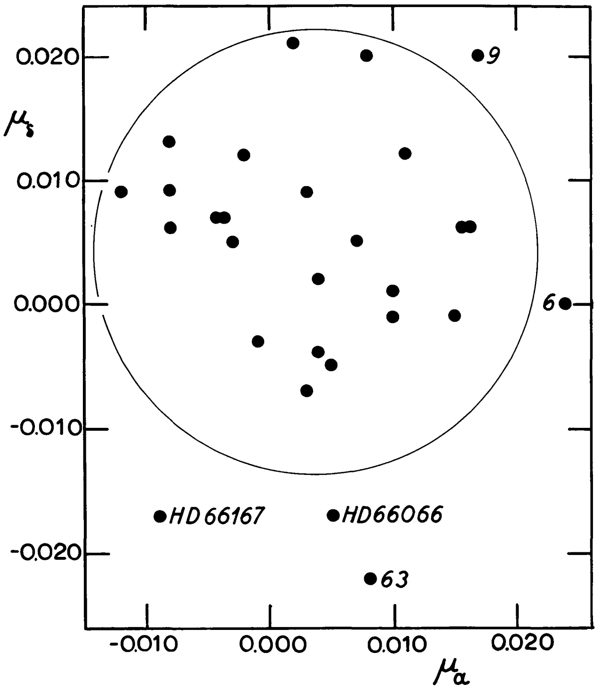


Figure 8 Proper motions from the SAO catalogue. A circle with radius $0''\!.018$/year is drawn. Stars outside could be considered non-members.

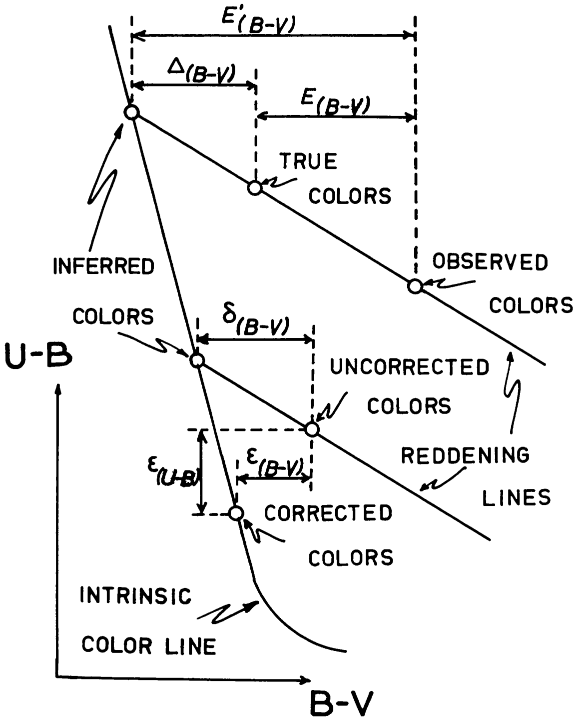


Figure 9 Schematic two-color diagram. All the quantities referred in the text are shown.

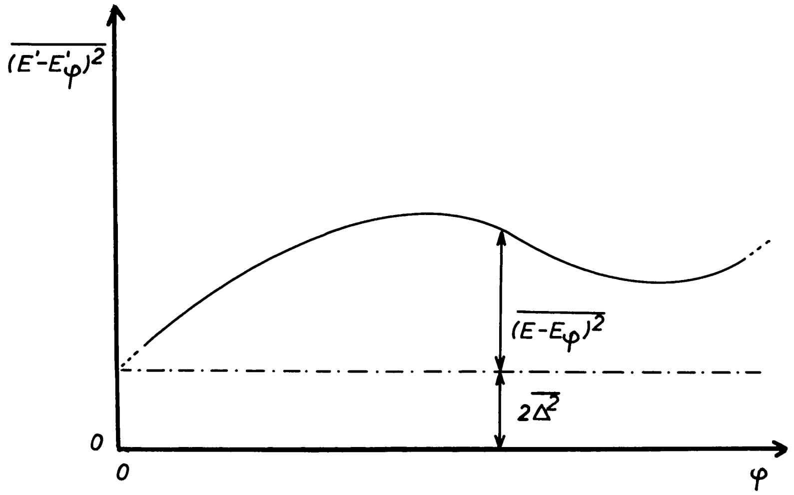


Figure 10 Schematic observed structural function. The dashed line divides the observed value of $\overline{(E' - E'_\varphi)^2}$ in its two contributors: $2\overline{\Delta^2}$ and $\overline{(E - E_\varphi)^2}$. As $\overline{(E - E_\varphi)^2}$ must be zero at $\varphi = 0$, and $\overline{\Delta^2}$ is independent of φ, the position and shape of the dashed line is that shown in the sketch.