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A CCD Search for Variable Stars of Spectral Type B in the Northern Hemisphere Open Clusters. IV. NGC 663

by

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ABSTRACT

We present results of the variability search in the field of the young open cluster NGC 663. In addition to the one β Cep-type variable known in this cluster, we found another one. It is a monoperiodic pulsator changing brightness with a period of 0.27640 d. In total, 19 new variables were discovered and the variability of 5 other ones was confirmed.

Out of all 24 variables in the observed field, 21 are probable cluster members. One SPB candidate and three eclipsing or ellipsoidal variables could be classified. Moreover, ten out of fourteen Be stars we observed vary in brightness. Only one of them shows periodic variations of the λ Eri-type, while the remaining ones exhibit irregular changes with the range up to 0.4 mag in the I_C band.

We also provide new VI_C photometry of 477 stars in the field of the cluster and check the consistence of the present photometry with cluster parameters derived earlier. The average cluster $E(V-I_C)$ color excess amounts to about 0.92 mag.

Key words: *Stars: early-type – binaries: eclipsing – open clusters and associations: individual: NGC 663*

1. Introduction

This is the fourth paper in the series presenting results of our variability search for B-type variables in young open clusters of the Northern Hemisphere. In the preceding papers we presented the results for the following open clusters: NGC 7128 (Jerzykiewicz *et al.* 1996, hereafter Paper I), NGC 7235 (Pigulski *et al.* 1997, Paper II), and NGC 6823 (Pigulski *et al.* 2000, Paper III) announcing the discovery of about 30 variables. In the present paper, we summarize the results for another young open cluster, NGC 663. These results are supplemented with the VI_C photometry of 477 stars in the observed field.

NGC 663 (C 0142+610, OCl 333) is a moderately rich young open cluster in Cassiopeia. It is located in the Perseus arm of the Galaxy in the neighborhood of many other open clusters (Trumpler 1930, McCuskey and Houk 1964, MacRobert 1989). The cluster is also the core of the Cas OB8 association. Its distance is estimated to be between 1.9 kpc and 2.8 kpc (McCuskey and Houk 1964 and Phelps and Janes 1994, respectively).

The cluster is known to contain one of the largest fractions of Be stars among all galactic clusters (Schild and Romanishin 1976, Sanduleak 1979, Mermilliod 1982, Slettebak 1985, Fabregat *et al.* 1996, Pigulski *et al.* 2001). In a $30' \times 30'$ square centered at the cluster, 29 Be stars are known. In the spectral range between B0 and B3 over 30% of all cluster members are Be stars (Pigulski *et al.* 2001). Since the cluster age is usually estimated to be between 9 Myr and 25 Myr (Tapia *et al.* 1991, Phelps and Janes 1994), the most massive members have already evolved off the main sequence and are now the brightest cluster stars (Fig. 1). In the richest part of the cluster, five B-type supergiants are known (Humphreys 1978).

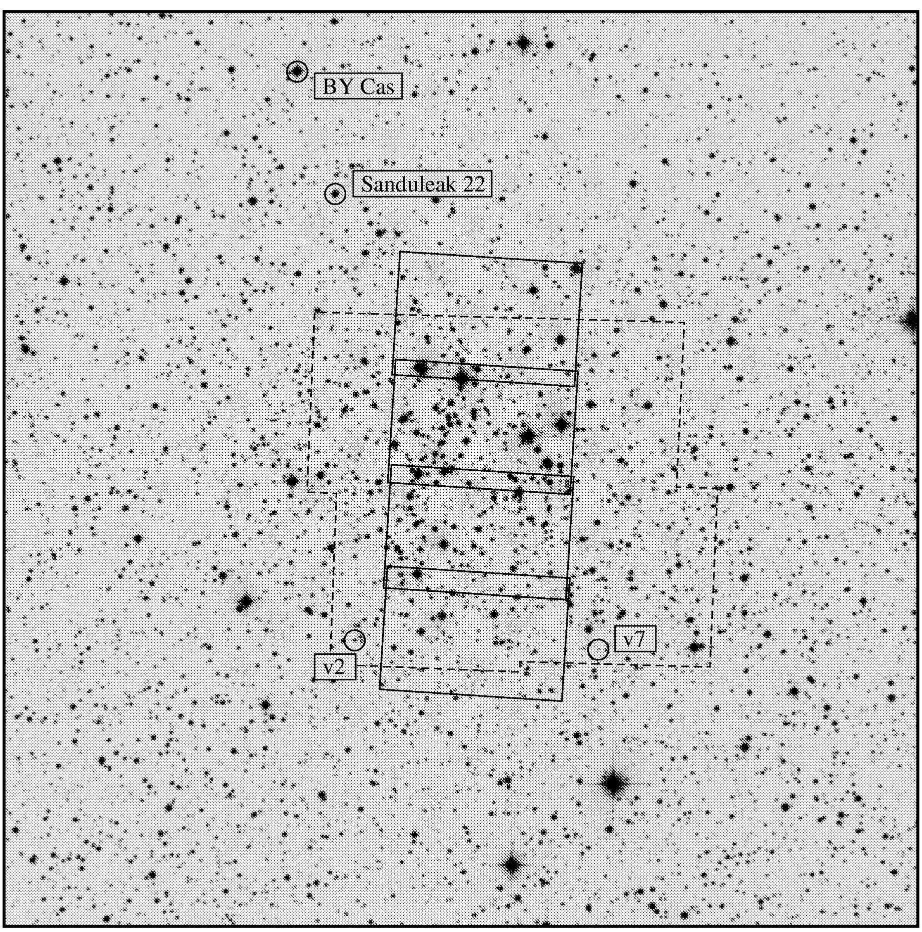

Fig. 1. A $30' \times 30'$ fragment of the POSS I plate centered on NGC 663. Four overlapping $6' \times 4'$ rectangles cover the field we searched for variables. The dashed line shows the borders of the area surveyed by Pietrzyński (1997). Four stars are encircled and labeled: BY Cas, Sanduleak 22, and the two variables, $v2$ and $v7$, discovered by Pietrzyński (1996, 1997), but not observed by us. North is up, East to the left.

There are two interesting objects in the vicinity of the cluster (Fig. 1): a 3.22-day classical Cepheid, BY Cas, and the low-mass X-ray/Be binary Sanduleak 22 = LS I +61°235 = RX J0146.9+6121 = X0146+612 (Motch *et al.* 1991). The latter exhibits 23.5-min periodic variations in X-rays (Hellier 1994) and Hα profile variations (Coe *et al.* 1993, Reig *et al.* 1997). Both these objects were supposed to be cluster members. The average radial velocity of NGC 663 stars, however, is about -33 km/s (Liu *et al.* 1989), while the radial velocity of Sanduleak 22 measured recently by Rodes *et al.* (1999) amounts to about -5 km/s and that of BY Cas, derived by Gorynya *et al.* (1995), is equal to -59 km/s. These data make the membership of both stars rather unlikely.

The relatively low number of the field stars contaminating the color-magnitude (C–M) diagram of NGC 663 is usually explained as the consequence of the absorption by the background molecular cloud (Phelps and Janes 1993). The foreground absorption is also significant resulting in a considerable reddening of the cluster. The average $E(B-V)$ color excess amounts to about 0.9 mag (Becker and Fenkart 1971, Mermilliod 1981, Phelps and Janes 1994), and is not uniform across the cluster (Johnson *et al.* 1961, van den Bergh and de Roux 1978).

NGC 663 has been a subject of many photometric studies. The most extensive *UBV* data are contained in the photoelectric measurements of Hoag *et al.* (1961), the CCD photometry of Phelps and Janes (1994), and photographic observations of Hoag *et al.* (1961), McCuskey and Houk (1964), Moffat and Vogt (1974), and van den Bergh and de Roux (1978). The Strömgren photometry of the cluster was made by Tapia *et al.* (1991) and Fabregat *et al.* (1996). The former authors provide also the *JHK* near-infrared photometry for a number of cluster stars. Old photographic photometry is available in the papers of Wallenquist (1929), Zug (1933), Becker and Günther (1947), and Becker and Stock (1954). Recently, new CCD $BV(RI)_{C}\mathrm{H}\alpha$ photometry of the cluster has been provided by Pigulski *et al.* (2001).

The MK spectral types are available for 18 stars from the field we observed. They come from papers of Hiltner (1956), Meadows (1961), Svolopoulos (1962), Hoag and Applequist (1965), McCuskey *et al.* (1974), Slettebak (1985), and Sears and Sowell (1997).

The cluster membership (by means of the proper motions) was studied by Gushee (1919), Hopmann and Haidrich (1959), and Latypov (1973).

2. Observations and Reductions

All our observations of NGC 663 were carried out at the Bialków Observatory of the Wroclaw University with the 60-cm reflecting telescope and 576×384 CCD camera with a Thomson TH 7883 chip as a detector. We started observing NGC 663 in 1997 with the aim of making a complete search for Be stars in the cluster. Fifteen overlapping fields were observed, covering an area of about 300 square arc minutes. These observations are not presented here; we reported them in a separate paper

(Pigulski *et al.* 2001, hereafter PKK), devoted exclusively to the study of the cluster Be stars.

The search for variability in the four fields shown in Fig. 1 was made in 1999, during 22 observing nights, from January 21 to September 20. Most frames (3362, over 800 per single field) were made in the Cousins I_C passband. In addition, about 640 frames were taken through the Johnson V filter. The exposure times ranged from 60 s to 120 s. A detailed map of the searched field, with all 715 stars detected in the I_C band, is shown in Fig. 2 (southern part) and Fig. 3 (northern part).

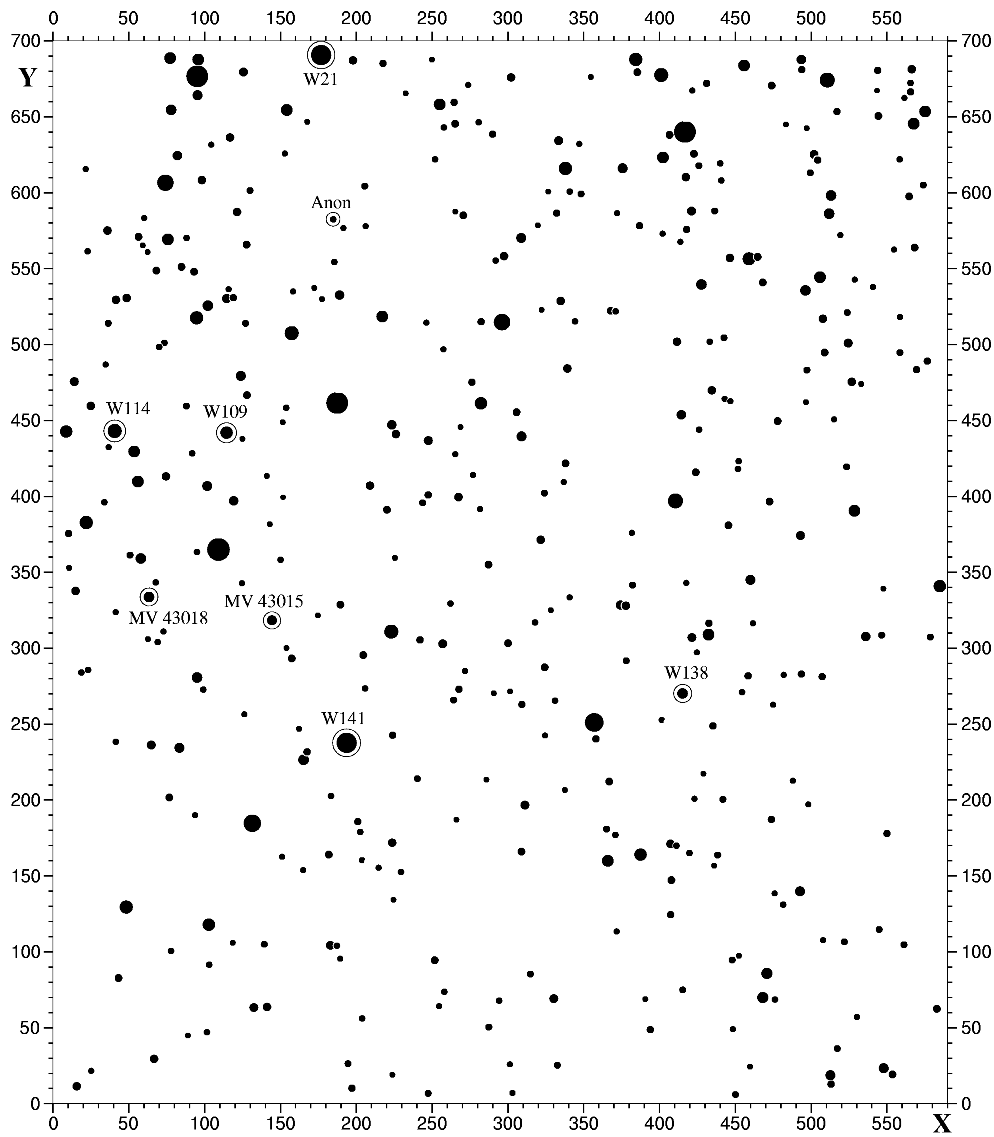

Fig. 2. Schematic view of the southern part of the observed field with all stars detected in the I_C band. Variable stars are encircled and labeled. The (X,Y) coordinates used in this figure are given in Table 4.

All frames were calibrated in the same way as in Paper I and then reduced using the point-spread-function fitting of DAOPHOT II package (Stetson 1987).

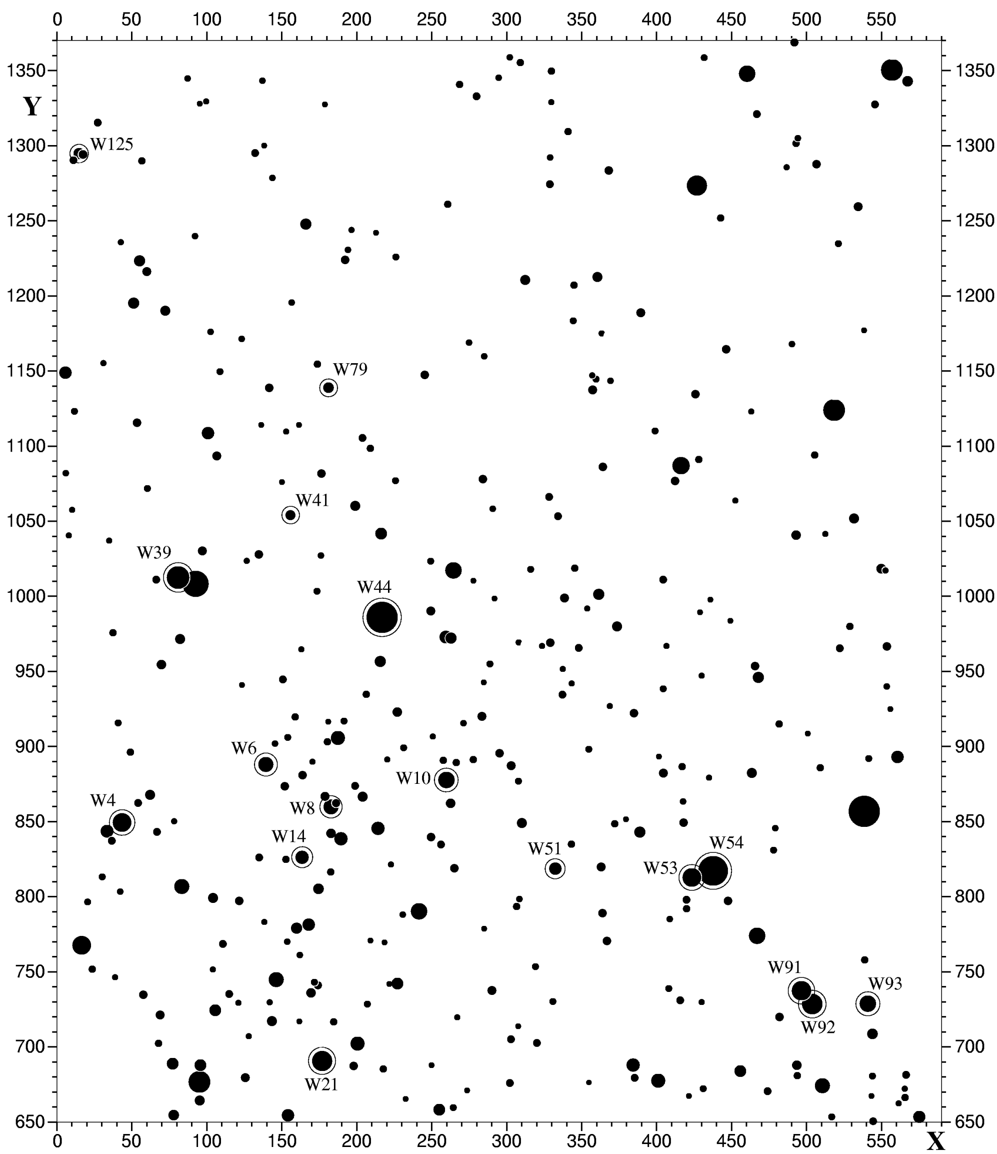

Fig. 3. The same as in Fig. 2 but for the northern part of the observed field.

3. Variable Stars

As in Paper III, we shall refer to a particular star in the cluster field using the existing numbering systems. For this purpose we shall add the following prefixes to the numbers: "W" for Wallenquist (1929), "H" for photoelectrically measured stars of Hoag *et al.* (1961), "HP" for the sequential number in the list of photographically measured stars by the same authors, "MV" for Moffat and Vogt (1974), and "T" for Tapia *et al.* (1991). These and other numbering systems are cross-referenced in Table 4.

The cluster was already the target of a variability search (Pietrzyński 1996, 1997). This author's observations covered roughly a square field (Fig. 1) overlapping in about 80% the area we observed. The survey carried out by Pietrzyński (1997, hereafter P97) led him to the discovery of seven variable stars, including one β Cep-type star. Out of those, five are located in our field. We confirm the variability of these five stars and announce the discovery of 19 other variables.

Reimann (1990) reported the variability of BD+60° 330, a foreground star located in the field of NGC 663, with a 0.4 mag range in the Strömgren y filter. We had this star in our field, but found it to be constant to within 0.01 mag.

The differential I_C-filter magnitudes of all 715 stars detected in the I_C band were searched for variability using the same methods as in Paper III. In particular, Fourier periodograms in the range between 0 d^{-1} and 30 d^{-1} were calculated for all stars. The differential magnitudes for all variables have been deposited in the *Acta Astronomica Archive*.

Table 1

Variable stars in NGC 663. ΔI_C stands for the range of the variability in the I_C band. Designations preceded by 'Sanduleak' (the last column) were taken from the list of Be stars in NGC 663 given by Sanduleak (1979, 1990)

Star	Period(s) [d]	ΔI_C [mag]	Member	Type of variability	Remarks
W 4	0.194047	0.040	yes	β Cep	$v4$ of P97
W 114	0.27640	0.029	yes	β Cep	
W 41	0.6698	0.033	yes	SPB	
W 79	1.3077	0.033	yes	Ellipsoidal	
W 125	0.5760	0.11	yes	Ellipsoidal	
MV 43018	0.461193	0.11	no	EA	$v1$ of P97
W 6	—	0.40	yes	Be	Sanduleak 14, $v5$ of P97
W 8	0.67298	0.035	yes	Be, λ Eri	Sanduleak 10
W 10	—	0.04	yes	Be	Sanduleak 9
W 21	—	0.21	yes	Be	Sanduleak 12
W 39	—	0.22	yes	Be	Sanduleak 16, BD+60°343 B
W 51	—	0.09	yes	Be	Sanduleak 29
W 53	—	0.13	yes	Be	Sanduleak 8, BD+60°333 B
W 92	—	0.22	yes	Be	Sanduleak 6, BD+60°332 A, B2 IV:e, $v6$ of P97
W 93	—	0.33	yes	Be	Sanduleak 5
W 141	—	0.07	yes	Be	Sanduleak 13, BD+60°341 B2 IIIe, $v3$ of P97
W 14	—	0.15	yes	unknown	
W 44	—	0.04	yes	Supergiant	BD+60°339, B6 Iab
W 54	—	0.07	yes	Supergiant	BD+60°333 A, B5 Iab
W 91	—	0.025	yes	unknown	
W 109	1.221	0.015	yes	unknown	non-sinusoidal
W 138	4.50	0.06	yes	unknown	
MV 43015	0.5476	0.019	no	unknown	
Anon.	—	0.18	unknown	unknown	

As we mentioned above, 24 stars in the field of NGC 663 were found by us to be variable. They are listed in Table 1 and indicated in Figs. 2 and 3. We shall now discuss them individually.

3.1. Pulsating Stars

Out of 24 variables detected in the field, three appear to be pulsating stars. Two of them, W 4 and W 114, are β Cep stars, while W 41 is probably an SPB star.

W 4 (HP 13, T 56) was already discovered to be a β Cep-type variable by P97. A B9 Ib MK spectral type for this star was reported by Svolopoulos (1962). It is obviously much too late for a β Cep-type star. However, the spectrogram used for classification by Svolopoulos (1962) may have been affected by the presence of a nearby star, W 3 = HP 42. The photometry made by Tapia *et al.* (1991) indicates that W 4 is, in fact, a reddened early B-type star. From the Strömgren m_1 and c_1 indices they found that the corresponding MK spectral type is B1 I. Because luminosity class obtained in this way is rather unreliable, the authors' conclusion that W 4 is a background star (see their Table 5), has no firm justification. As we shall show later, the star falls on the cluster main sequence and, therefore, is almost certainly its member.

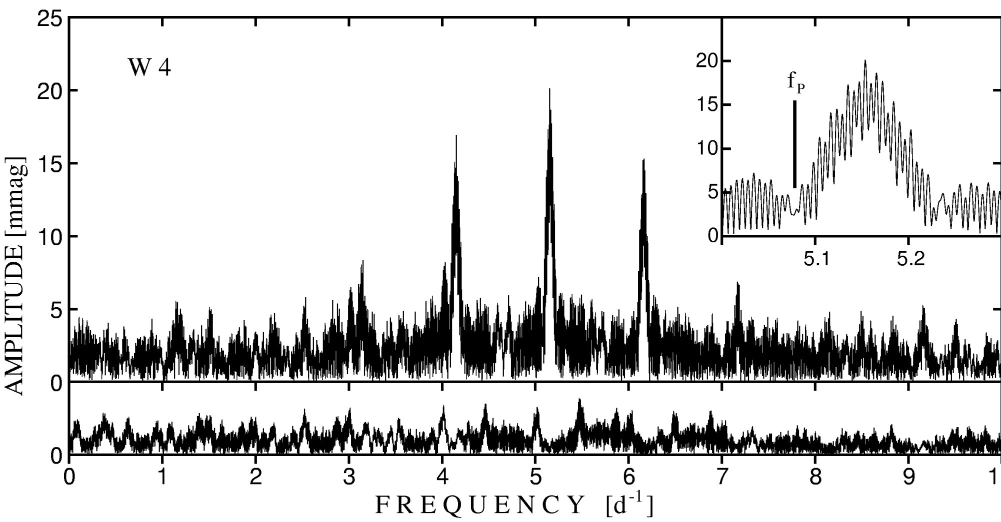

Fig. 4. *Top:* Fourier frequency spectrum of the 1999 I_C-filter observations of the β Cep star W 4. The inset shows the structure of the central peak. Note the position of $f_P = 5.078$ d^{-1}. *Bottom*: after prewhitening with frequency 5.15340 d^{-1}.

Fourier periodogram of our I_C-filter observations of W 4 (Fig. 4) reveals the presence of a single periodicity at frequency 5.15340 ± 0.00004 d^{-1}. As can be seen from the inset in Fig. 4, there could be some ambiguity in the determination of the true frequency due to the high nearby aliases. This is a consequence of the distribution of our observations in time: one night in January and the main run in August–September 1999 with only a few short nights in between. After removing the 5.15340 d^{-1} signal, we found no significant peaks with amplitudes larger than about 4 mmag. As shown in Fig. 5 and Table 2, the semi-amplitudes in the I_C and V bands are the same to within one standard deviation. In Table 2 we give the parameters of the sine-curve fitting to the differential data of W 4 and the remaining periodic pulsators discussed in this paper.

Table 2

Parameters of the sine-curve fitting to the photometric data of the pulsators discovered in NGC 663. The numbers in parentheses denote the mean errors with the leading zeroes omitted. The phases are given for epoch HJD 2 451 000. RSD stands for the standard deviation of the residuals from the fit.

Star	Frequency $[\mathrm{d}^{-1}]$	Filter	$N_{\rm obs}$	Semi-ampl. [mmag]	Phase [rad]	Time of max. light − HJD 2451000	RSD [mmag]
W 4	5.15340	V	284	20.6(09)	1.69(5)	330.5547(14)	7.0
		$I_{\rm C}$	1039	19.9(03)	1.71(2)	398.6645(05)	11.2
W 114	3.6180	V	97	13.9(11)	5.66(8)	434.1760(34)	7.5
		$I_{\rm C}$	741	14.4(03)	5.66(2)	433.0704(10)	6.1
W 41	1.4929	$I_{\rm C}$	718	16.7(08)	5.13(4)	432.671(5)	13.9

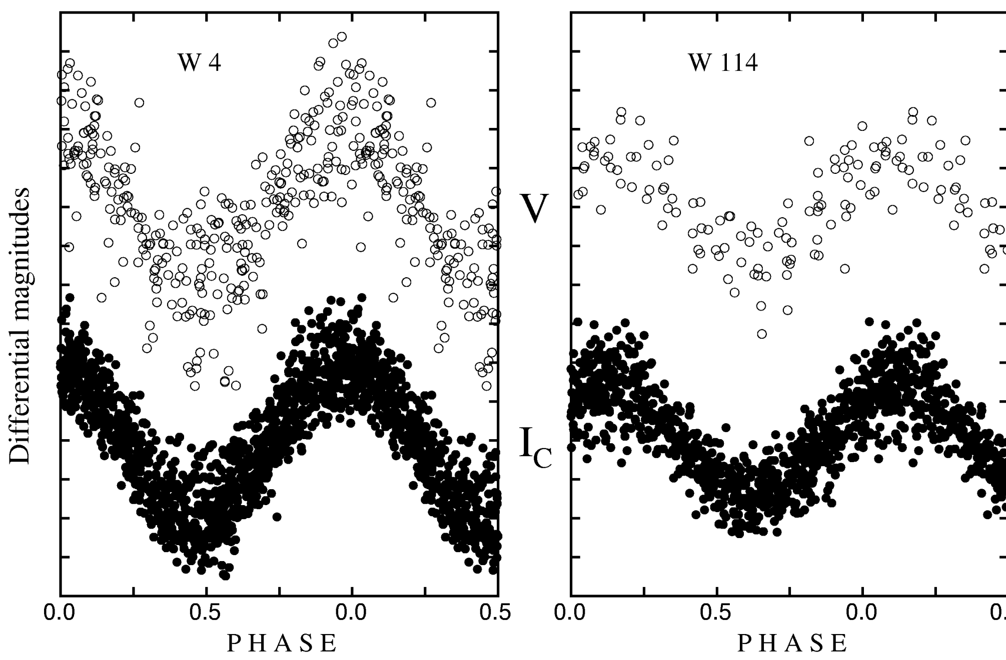

Fig. 5. Differential V (open circles) and $I_{\rm C}$ (dots) light curves of W 4 (left panel) and W 114 (right panel) folded respectively with the periods of 0.194047 d and 0.27640 d. The data for W 114 were freed from the contribution of the f_2 and $2f_2$ terms (see text). The ordinate ticks are separated by 0.01 mag. Phase 0.0 was chosen arbitrarily.

Surprisingly, the period we derived for W 4 does not match that found by P97. From nine times of maximum light listed by this author we derived a period of 0.19692 ± 0.00006 d, closest to the value of 0.197 d given in his paper. The corresponding frequency, $f_{\rm P} = 5.078 \pm 0.002$ d^{-1}, is indicated in Fig. 4 (inset). All but two times of maximum light given by P97 can be, however, fitted with our period. The remaining two result in $O-C$ residuals equal roughly to half our period. Because both P97 and our observations were made in the Cousins $I_{\rm C}$ band, we can also compare the amplitudes. We find the semi-amplitude of about 20 mmag, whereas it is about 14 mmag in the observations of P97. While the amplitude change is possible in a β Cep star, it is rather unlikely that the period decreased by over 4 minutes during the two years which passed between P97's and our observations of W 4. We do not know how to explain this discrepancy. Unfortunately, reanalysis of the observations of W 4 presented by P97 is not possible because the original data have been lost (Pietrzyński, private communication).

The other β Cep star found in the field is W 114. No spectral type is available for this star, but it lies on the cluster main sequence in the position corresponding roughly to a B2–B3 star. The periodogram (Fig. 6) reveals a periodicity with the frequency $f_1 = 3.6180 \pm 0.0010$ d^{-1} and a semi-amplitude of about 14 mmag in both I_C and V band (Table 2). Subsequent prewhitening (Fig. 6) results in the detection of another peak at frequency $f_2 = 1.639$ d^{-1} and then its harmonic at 3.291 d$^{-1} \approx 2f_2$. The peaks seem to be significant. If real, the variations with frequency f_2 could be probably attributed to the SPB or ellipsoidal variations. The I_C-filter data of W 114 phased with the period $P_1 = f_1^{-1}$ are shown in Fig. 5.

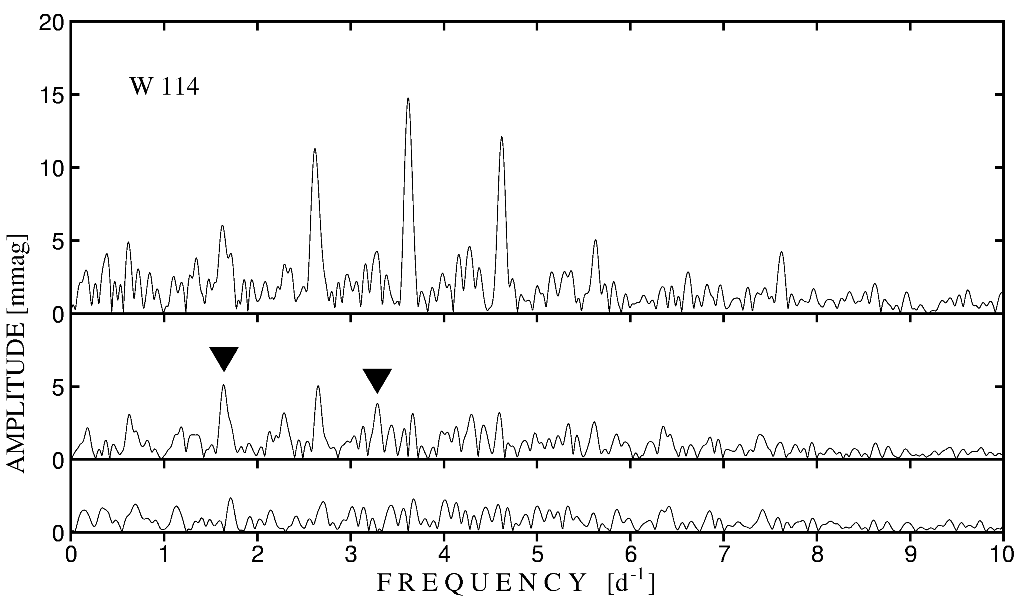

Fig. 6. *Top*: Fourier frequency spectrum of the 1999 I_C-filter observations of W 114. *Middle*: after prewhitening with the frequency $f_1 = 3.6180$ d^{-1}. The second frequency, $f_2 = 1.638$ d^{-1} and its harmonic, $2f_2 = 3.287$ d^{-1}, are indicated with triangles. *Bottom*: after prewhitening with f_1, f_2, and $2f_2$.

The third pulsator found in NGC 663 is star W 41 = HP 80. It has no available spectral type, but lies on the cluster main sequence in the position corresponding to a mid B-type star. The periodogram of the I_C-filter photometry of this star reveals a single periodicity with a frequency of 1.4929 d^{-1} (Fig. 7). The corresponding period, 0.6698 d, is within the range occupied by the SPB stars. We shall therefore classify this star tentatively as an SPB variable.

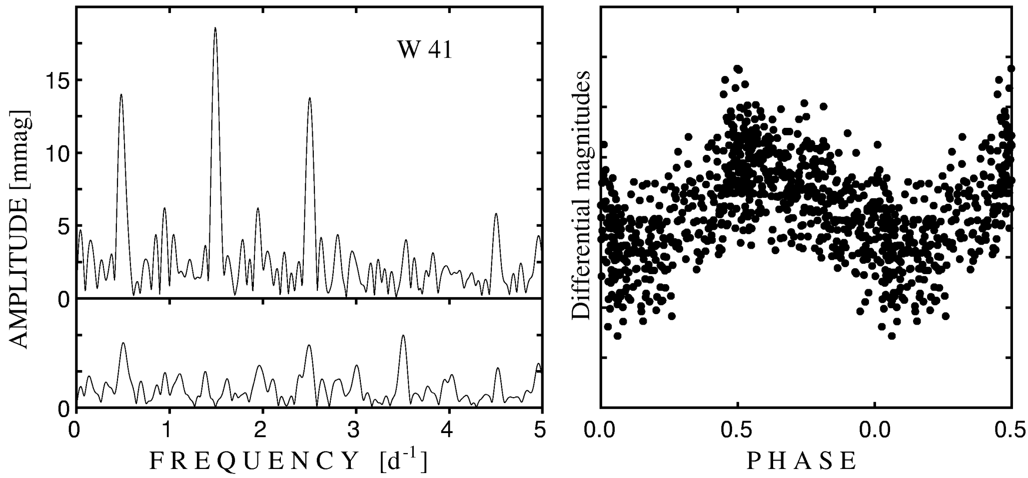

Fig. 7. *Top left*: Fourier frequency spectrum of the 1999 I_C-filter observations of the cluster SPB candidate, W 41. *Bottom left*: after prewhitening with the frequency $f = 1.4929$ d^{-1}. *Right*: Phase diagram of the same data folded with $P = f^{-1} = 0.6698$ d. The ordinate ticks are separated by 0.02 mag.

3.2. Eclipsing and Ellipsoidal Variables

Two eclipsing binaries in the field of NGC 663 were discovered by Pietrzyński (1996, 1997). His variable $v2$ = MV 42034 was outside our search field (Fig. 1), but the other one, $v1$ = MV 43018, was observed by us. From the eight times of minimum light published by P97 in his Table 2 (the number of cycles for the first minimum was corrected from -363 to -362) we derived the following ephemeris:

$$\text{Min I} = \text{HJD } 2450338.381(3) + 0.461153(13) \times E \quad (1)$$

where E is the number of elapsed cycles and the numbers in parentheses denote the mean errors with the leading zeroes omitted. From our I_C-filter data, we derived 14 new times of minimum light using the same method as that described by Kopacki and Pigulski (1995). The times of minimum light are listed in Table 3. The ephemeris which describes all 22 times of minimum light for MV 43018 is the following:

$$\text{Min I} = \text{HJD } 2450338.386(9) + 0.461193(4) \times E. \quad (2)$$

The star is a foreground object (Section 4). The eclipses are partial and of similar depth (Fig. 8). From simple considerations, taking into account the orbital period, the depth and duration of the eclipses, under assumption that both stars are main sequence objects, we conclude that the system consists of two M4–M5 dwarfs. The observed magnitude and color of the star are consistent with this conclusion.

The other two stars, W 79 = HP 72 and W 125, are very likely ellipsoidal systems. The former seems to belong to the cluster, the latter is a foreground object. The phase diagrams of their light changes in the I_C band are also shown in Fig. 8.

Table 3

The times of minimum light in the I_C-filter for the EA-type eclipsing binary MV 43018 in the field of NGC 663. Numbers in parentheses denote the mean errors, in the units of 0.0001 d. The cycles E and $O-C$ values were calculated with Eq. (2).

HJD of T_{min} (2451000+)	E	$O-C$ [days]	HJD of T_{min} (2451000+)	E	$O-C$ [days]
425.4173(17)	2357	−.0008	432.3384(07)	2372	+.0024
426.3398(13)	2359	−.0007	433.2592(12)	2374	+.0008
427.2645(13)	2361	+.0016	434.6409(10)	2377	−.0011
428.6458(10)	2364	−.0007	435.5651(08)	2379	+.0008
429.5688(10)	2366	+.0000	436.4877(12)	2381	+.0010
430.4923(09)	2368	+.0011	437.4104(08)	2383	+.0013
431.4130(10)	2370	−.0006	441.5630(19)	2392	+.0031

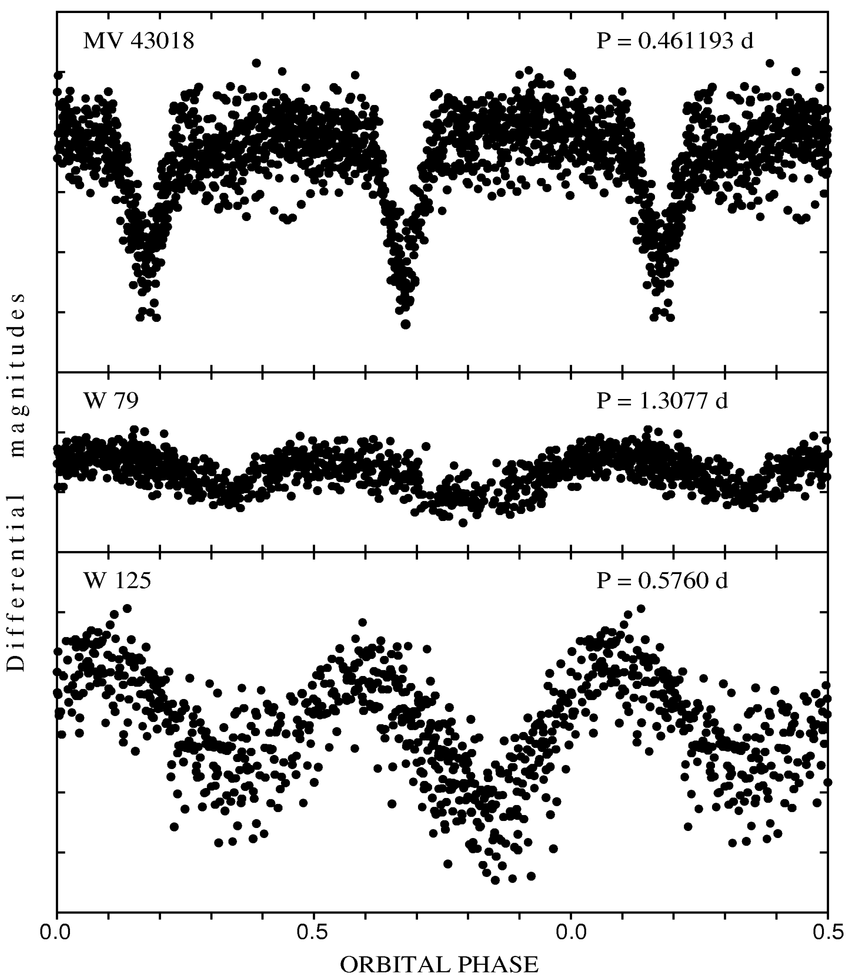

Fig. 8. Differential I_C-filter observations of three variables, MV 43018 (top), W 79 (middle), and W 125 (bottom) folded with the indicated periods. Ordinate ticks are separated by 0.05 mag. Phase 0.0 was chosen arbitrarily.

3.3. *Be Stars*

As we mentioned in the Introduction, NGC 663 contains a large number of Be stars. Variability on different time scales is rather a rule in these stars. Up-to-date, only three Be stars in NGC 663 were announced to be variable, all discovered by P97. These are: W 141 = H 6 = Sanduleak 13 (B2 IIIe), an extreme Be star according to Shild and Romanishin (1976), W 6 = HP 29 = Sanduleak 14, and W 92 = BD+60° 332 A = Sanduleak 6 (B2 IV:e). The spectral types were taken from Slettebak (1985), designations preceded by 'Sanduleak' come from the list of Be stars in NGC 663 compiled by Sanduleak in 1979 and extended in his 1990 paper (Sanduleak 1979, 1990). In the notation of P97, the three stars were respectively designated as variables $v3$, $v5$, and $v6$. The last star was classified by P97 as an RR Lyr variable with a 0.94-day period. This is clearly a misidentification. Although quasi-periodic changes with a period of the order of 1 day can be also seen in our photometry, they are superimposed on changes with a much longer time scale and larger brightness range.

We had 14 Be stars in our field. Out of them, 10 appeared to be variable (Table 1). Only one Be star, W 8 = HP 31, shows periodic variations. The period of these variations amounts to 0.673 d, so that it can be classified as a λ Eri-type variable. The other Be variables show complicated light changes on different time scales. A detailed discussion of the light variations of all Be stars in NGC 663 has been given by PKK.

3.4. *Other Stars*

Out of the remaining eight variables, three appear to be periodic. Two of them, W 109 and W 139, seem to be the cluster members. Although the period of W 109, 1.221 d, falls within the range of periods of SPB stars, its light curve is nonsinusoidal. It is therefore rather unlikely that this is an SPB star.

Two of the four observed cluster early-type supergiants, W 44 = BD+60° 339 (B6 Iab) and W 54 = BD+60° 333 A (B5 Iab) also vary in brightness. Photometric changes they show have a range below 0.1 mag and are irregular in shape. This type of behavior is rather common in supergiants.

4. $VI_{\rm C}$ Photometry

Transformation to the standard system was done in the same way as in Paper III. This time, however, our observations were tied to the photometry made by PKK which included much more stars in the field of NGC 663 than the sample searched for variability. For comparison of the *BV* photometry of PKK with previous works, we refer the reader to that paper.

The limiting magnitudes of the present photometry are 17.6 mag in V and 17.2 mag in $I_{\rm C}$. Since for the cluster main-sequence stars, $V = 17.6$ mag corresponds to $I_{\rm C} = 16.4$ mag, the $I_{\rm C}$ photometry is ≈ 0.8 mag deeper. Because a color is needed for transformation, the standard photometry is not given for all stars searched for variability. It is also worthwhile to mention that the VI_C photometry presented in this paper has much better internal accuracy than that of PKK because we used all observations to average the instrumental magnitudes transformed later to the standard system. For the faintest stars presented in Table 4, the accuracy is of the order of 25 mmag and 5 mmag, respectively for V and I_C, whereas for the bright isolated stars it amounted to about 1 mmag and 0.3 mmag.

The VI_C photometry of 477 stars in the field of NGC 663 is given in Table 4. The full version of Table 4 is available in the electronic form from the *Acta Astronomica Archive*. For reader's convenience, we present here only those entries which refer to the variable stars (without cross-identifications).

The equatorial coordinates given in Table 4 were calculated from the *Guide Star Catalogue* (GSC) positions of 62 stars in the field and are accurate to $0\farcs1$.

Table 4

VI_C photometry, coordinates and cross-identifications of stars in the observed field in NGC 663.

Star name	X [pix]	Y [pix]	$\alpha_{2000.0}$	$\delta_{2000.0}$	V [mag]	$V-I_C$ [mag]
W 4	43.5	849.4	$1^h46^m38\fs96$	$+61°14'06\farcs3$	11.042	0.628
W 114	40.7	443.1	$1^h46^m39\fs74$	$+61°09'52\farcs0$	12.378	0.658
W 41	155.9	1054.1	$1^h46^m28\fs93$	$+61°16'13\farcs1$	14.334	0.812
W 79	181.2	1138.8	$1^h46^m26\fs61$	$+61°17'05\farcs8$	14.118	0.751
W 125	14.8	1294.8	$1^h46^m40\fs83$	$+61°18'45\farcs3$	14.251	1.159
MV 43018	63.3	333.8	$1^h46^m37\fs93$	$+61°08'43\farcs4$	14.644	1.174
W 6	139.4	888.0	$1^h46^m30\fs60$	$+61°14'29\farcs3$	11.952	0.927
W 8	182.8	859.8	$1^h46^m26\fs87$	$+61°14'11\farcs2$	12.230	0.790
W 10	259.7	877.7	$1^h46^m20\fs19$	$+61°14'21\farcs6$	11.796	0.854
W 21	176.8	690.7	$1^h46^m27\fs64$	$+61°12'25\farcs5$	10.659	0.699
W 39	80.9	1012.6	$1^h46^m35\fs49$	$+61°15'48\farcs0$	10.295	0.929
W 51	332.3	818.6	$1^h46^m13\fs99$	$+61°13'43\farcs8$	13.196	0.893
W 53	423.5	812.8	$1^h46^m06\fs09$	$+61°13'39\farcs1$	11.320	0.990
W 92	503.8	728.5	$1^h45^m59\fs27$	$+61°12'45\farcs6$	10.567	0.784
W 93	540.9	728.7	$1^h45^m56\fs07$	$+61°12'45\farcs3$	11.809	0.970
W 141	193.6	237.7	$1^h46^m26\fs80$	$+61°07'41\farcs8$	10.651	0.802
W 14	163.6	826.3	$1^h46^m28\fs59$	$+61°13'50\farcs5$	12.661	0.758
W 44	216.9	986.0	$1^h46^m23\fs74$	$+61°15'29\farcs8$	8.433	0.800
W 54	437.7	817.2	$1^h46^m04\fs85$	$+61°13'41\farcs8$	8.862	0.951
W 91	496.6	737.4	$1^h45^m59\fs88$	$+61°12'51\farcs2$	10.959	0.858
W 109	114.4	441.9	$1^h46^m33\fs37$	$+61°09'50\farcs5$	13.115	0.686
W 138	415.3	270.2	$1^h46^m07\fs62$	$+61°07'59\farcs9$	13.898	0.564
MV 43015	144.4	318.3	$1^h46^m30\fs95$	$+61°08'32\farcs8$	14.916	1.077
Anon.	184.7	582.5	$1^h46^m27\fs09$	$+61°11'17\farcs7$	—	—

PKK derived an age of 20–25 Myr, distance modulus of 11.6 mag, and the average reddening, $E(R-I)_{\mathrm{C}} = 0.54$ mag using the $(RI)_{\mathrm{C}}$ photometry we mentioned in the Introduction. Since the VI_{C} photometry reported in this paper was tied to that presented by PKK, we do not derive independent cluster parameters here. Instead, we check whether these parameters fit also the new photometry. The C–M diagram, V *vs.* $V-I_{\mathrm{C}}$, for 477 stars in the field of NGC 663 is shown in Fig. 9 (left). The colors of stars and their magnitudes are affected by differential reddening. For this reason, following the procedure used by PKK, we have removed the differential component of the reddening (see PKK for the details). The procedure includes the calculation of the reddening map; simultaneously, a selection of non-members is performed. The non-members identified in this way are shown with crosses in Fig. 9 (left).

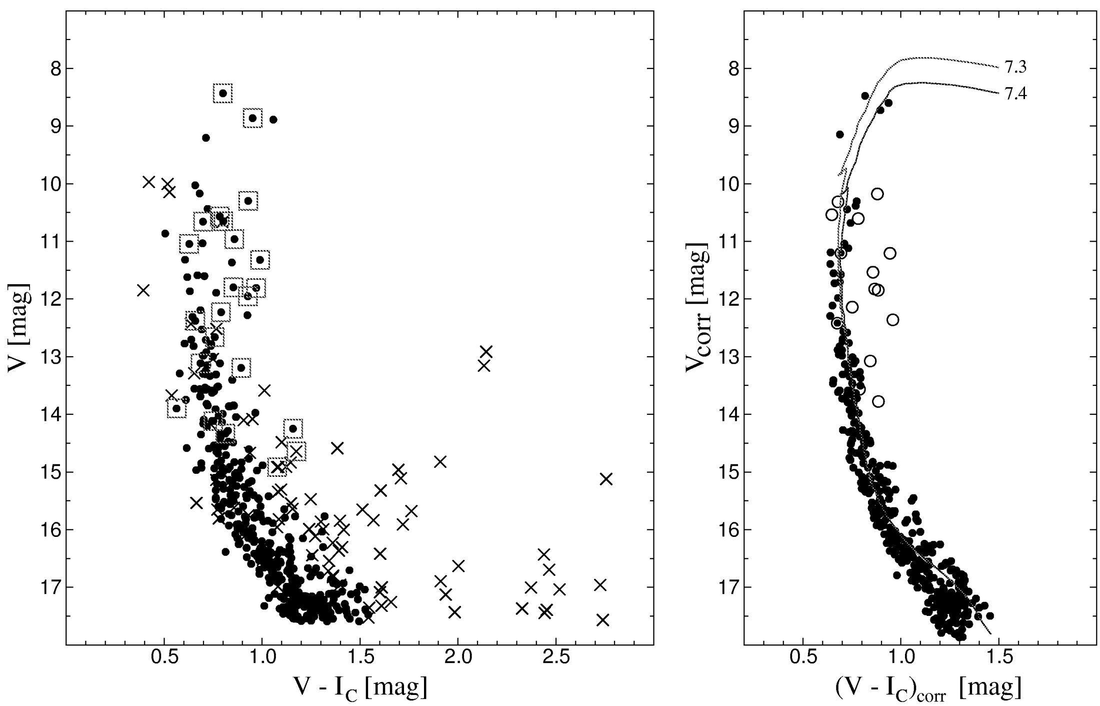

Fig. 9. *Left*: V *vs.* $V-I_{\mathrm{C}}$ color–magnitude diagram for NGC 663. Crosses denote stars selected as non-members. Variables are enclosed in open squares. *Right*: The color–magnitude diagram corrected for the differential components of the reddening and extinction. Stars selected as non-members are not shown. Open circles denote Be stars, encircled dots, the two β Cep-type stars. The two continuous lines are the isochrones of Bertelli *et al.* (1994) for $Y = 0.28$ and $Z = 0.02$. The true distance modulus of 11.6 mag and $E(V-I_{\mathrm{C}}) = 0.92$ mag were adopted. The numbers to the right of the isochrones are the logarithms of the age in years.

The C–M diagram corrected for differential component of the reddening is shown in Fig. 9 (right). Following PKK, we adopted a distance modulus of 11.6 mag. The average $E(V-I_{\mathrm{C}})$ color excess was found to be equal to 0.92 mag. Since Be stars show usually additional intrinsic reddening, their photometry was not used in the calculation of the reddening map. However, we corrected the colors and magnitudes of these stars for the differential component of reddening, according to the derived reddening map. The positions of Be stars in the dereddened C–M diagram are shown with open circles in Fig. 9 (right). It can be clearly seen that indeed most of them show an extra reddening, probably of circumstellar origin. In terms of $(V - I_C)$ color, Be stars are 0.13 mag redder, on average, than non-Be stars of similar magnitude.

5. Discussion and Conclusions

As can be seen in Fig. 9, the two β Cep-type stars in NGC 663 are, as most stars of this type, in the advanced phase of the core-hydrogen burning. It can be also seen that about 10 constant stars fall within the range of magnitudes spanned by the two variables. A similar incidence of variability among early B-type stars was found in h and χ Per (Krzesiński and Pigulski 1997, Krzesiński *et al.* 1999). It seems, therefore, that in addition to h and χ Per, NGC 663 is another young cluster in which: (i) Be and β Cep-type stars coexist, (ii) only a small fraction of stars falling into the β Cep instability strip show detectable brightness variations. Conclusion (ii) stays in a clear contrast to the large number of variables of this type observed in the three southern clusters of similar age, NGC 3293, NGC 4755, and NGC 6231 (Balona 1994, Balona and Koen 1994, Balona and Laney 1995). Taking into account a 3–4 kpc difference in the galactocentric distance of the two groups of clusters, we can speculate that the metallicity gradient in the Galaxy may be responsible for this difference. Before final conclusion on this will be reached, however, we need a direct measurement of the metal abundance in early B-type stars (including β Cep stars) in the southern and northern clusters. Moreover, more clusters and/or associations should be searched for variability in order to improve the statistics. We are going to continue our variability search in order to achieve this goal.

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