1997AcA....47..365P

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# A CCD Search for Variable Stars of Spectral Type B in the Northern Hemisphere Open Clusters
# II. NGC 7235

by

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ABSTRACT

We report the discovery of nine variable stars in a $4' \times 6'$ field covering NGC 7235. The variable stars include a $\beta$ Cep star, a Be short-period variable of the $\lambda$ Eri type, a Mira, a W UMa eclipsing binary, a candidate $\alpha$ Cyg variable, and a probable eclipsing binary. The remaining three variable stars could not be classified because of insufficient data. The $\beta$ Cep star, the $\lambda$ Eri variable, the candidate $\alpha$ Cyg variable, and the probable eclipsing binary are members of the cluster. We found no SPB stars in NGC 7235.

For a number of stars in our field we also provide the $I$ magnitudes and the $R-I$, $V-I$, and $B-V$ color indices on the $BV(RI)_C$ system of Johnson, Kron and Cousins. We find large systematic effects for the faint photographic $V$ magnitudes.

We define an $\alpha$ index which is a measure of the equivalent width of the H$\alpha$ line. We give the $\alpha$ index for 64 brightest stars in our field. Our $\alpha$ index revealed the Be nature of the above-mentioned $\lambda$ Eri variable.

**Key words:** *Stars: early-type – Stars: oscillations – binaries: eclipsing – Stars: emission-line, Be – open clusters and associations: individual: NGC 7235*

## 1. Introduction

This is another paper containing results of our CCD search for B-type variables in young open clusters of the Northern Hemisphere. The first paper of the series (Jerzykiewicz *et al.* 1996, hereafter Paper I), was devoted to NGC 7128. The results included the discovery of six variable stars and accurate photometry of two known variables, as well as new *BVI* photometry of 30, and *VI* photometry of over 200 stars. In the present paper, we give the results of the variability search in another young open cluster, NGC 7235, also supplemented with $BVRI$ photometry. In addition – for the first time in this program – we report CCD observations with H$\alpha$ filters.

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1997AcA....47..365P



NGC 7235 (IAU C2210+570) is a small cluster of Trumpler type III2p (Ruprecht 1966) in Cepheus. The cluster has an angular diameter of about 5′ and contains about thirty B-type stars. The age of NGC 7235 has been estimated by Lindoff (1968) and Stothers (1972) for 10 and 25 Myr, respectively. Depending on the method used, the estimates of the cluster's distance modulus range from 12.5 to 13.1. The reddening is not uniform across the cluster: the color excess, $E(B-V)$, varies from 0.8 to 1.0 mag (Johnson *et al.* 1961, Schmidt 1963).

Hoag *et al.* (1961, henceforth HJ) were the first to carry out *UBV* photometry of NGC 7235. Subsequent photometry of the cluster includes the photographic work of Becker (1965) and Moffat (1972) and photoelectric observations of nine faint stars by García-Pelayo and Alfaro (1984). The two-color diagram clearly indicates the presence of early B stars, with the bluest ones corresponding to the spectral type of about B0. The cluster is also known to contain the supergiant HDE 239886 ($V = 8.80$, B9 Iab), designated as star No. 1 in the photoelectric sequence of HJ (see also Hoag and Applequist 1965).

Preliminary results of our search for variable stars in NGC 7235 were already reported by Pigulski *et al.* (1995). In this paper we present final results, based on all our data.

## 2. Observations and Reductions

The observations were obtained at the Bialków station of the Wroclaw University Observatory with a 60-cm Cassegrain telescope and the CCD camera described in Paper I. In August 1996 we added an autoguider to our equipment. Before August 1995 the observations were taken with a filter which had a double-passband transmission. One band covered the range between 380 and 520 nm, and the other extended from 750 to 1100 nm. For the highly reddened stars of NGC 7235, most of the light was detected through the near-infrared passband of the filter. In the following we shall denote this filter as $r_{\rm B}$. The same notation will be used for the instrumental magnitudes obtained with it.

A total of about 650 frames were taken with the $r_{\rm B}$ filter on 13 nights in 1994 and on 7 nights in 1995. Although inconsistent with any standard photometric system, and therefore left on the instrumental system, these observations turned out to be suitable for our purpose of assessing light variability and deriving periods.

In the summer of 1995 we acquired a new set of *BVRI* filters, described in detail in Paper I. The observations of NGC 7235 with these filters spanned the interval between October 11, 1995 and December 22, 1996, but most of the data were obtained between May 31 and August 9, 1996. Altogether we took 206, 96 and 226 frames with the $V$, $R$ and $I$ filters, respectively. These observations were used to verify and improve the results of the search with the $r_{\rm B}$ filter. A limited number of $B$-filter observations was also taken for deriving $B-V$ color indices. Depending on the filter, sky transparency and seeing, the exposure times for the search frames ranged from 60 to 100 s. A CCD image of the field of NGC 7235, covering an area of $4' \times 6'$, is shown in Fig. 1.

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1997AcA....47..365P



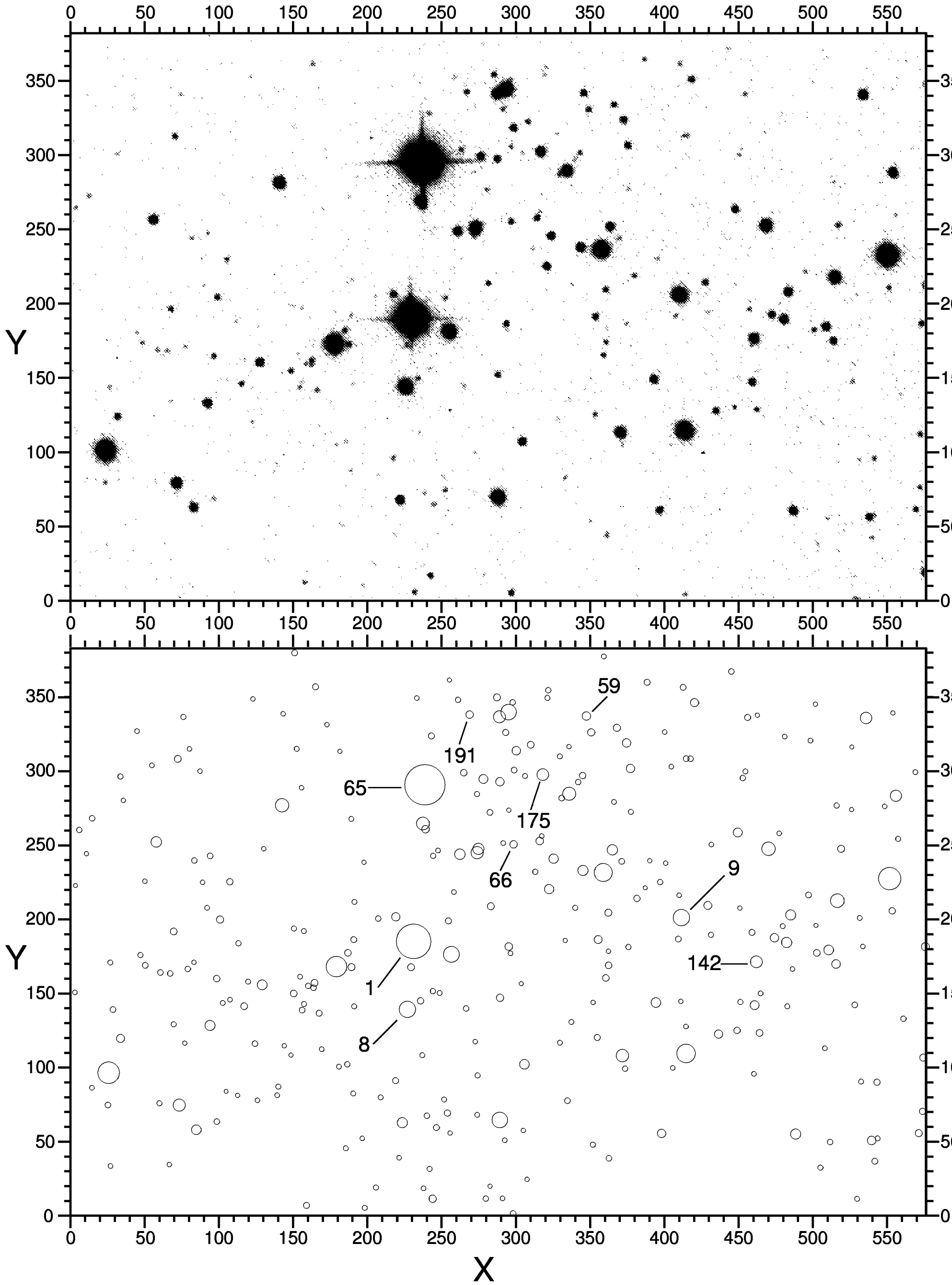


Fig. 1. A 60-s $r_{\rm B}$ -filter exposure of NGC 7235 (upper panel) and the 297 stars that were checked for variability (lower panel). The stars we found to be variable are labeled in the lower panel. North is up, east to the left.

All search frames were calibrated in the way described in Paper I. The frames were then reduced by means of Stetson's (1987) DAOPHOT package. A total of 297 stars were identified in the field.

In addition to the $r_{\rm B}$ and $BVRI$ observations, we also observed the cluster with a pair of H$\alpha$ filters. These observations are described below, in Section 5.

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## 3. Variable Stars

Using the DAOPHOT magnitudes for all identified stars in the field, we formed differential magnitudes for each star separately. Then, the differential magnitudes were used to find variable stars. This procedure has been described in detail in Paper I.

The first numbering system for NGC 7235 was introduced by HJ. Becker (1965) retained the HJ numbers for 25 photoelectrically measured stars and affixed numbers from 26 to 121 to stars with his own photometry. In the present paper, we shall use the numbering system of HJ and Becker (1965), extending it for previously unnumbered stars. Our numbers start with 122. Since, however, stars 98, 99, and 120 could not be found in Becker's (1965) Fig. 1, they may be among the stars that have our numbers.

Prior to our study, no variable stars were known in NGC 7235. The variables we detected are identified in Fig. 1 and are listed in Table 1. Tables with the differential magnitudes have been deposited in the *Acta Astronomica Archive*; the tables can be retrieved *via* anonymous ftp as explained in the editorial note on the cover page. We shall now discuss the variables individually.

Table 1

Variable stars in NGC 7235.

| Star | Period(s) [d] | Range [mag] | | | | Type of variability |
|---|---|---|---|---|---|---|
| | | $r_B$ | $V$ | $R$ | $I$ | |
| 1 | 7.273 or alias | 0.03 | 0.03 | 0.04 | 0.04 | $\alpha$ Cyg? |
| 8 | 0.202890 | 0.024 | 0.029 | 0.030 | 0.028 | $\beta$ Cep |
| | 0.177898 | 0.023 | 0.022 | 0.024 | 0.022 | |
| 9 | 0.86133 or alias | 0.14 | 0.03 | 0.03 | 0.03 | $\lambda$ Eri |
| 59 | – | 0.1 | 0.0 | 0.0 | 0.0 | Unknown |
| 65 | – | 0.02 | 0.05 | 0.05 | 0.05 | Irregular |
| 66 | 1.8741 or alias | 0.09 | 0.10 | 0.12 | 0.07 | Eclipsing? |
| 142 | – | 0.02 | 0.07 | 0.07 | 0.04 | Irregular? |
| 175 | – | 1.4 | $>0.6$ | 1.5 | 1.1 | Mira |
| 191 | 0.2800284 | 0.38 | 0.38 | 0.44 | 0.42 | W UMa |

**NGC 7235-1 = HDE 239886.** This is the B9 Iab supergiant mentioned in the Introduction. The star was saturated in almost all our frames. However, with a large fitting radius of the point spread function (PSF), DAOPHOT was still able to derive reliable magnitudes using only non-saturated pixels. Obviously, the accuracy of the magnitude determination for this star was lower than for other non-saturated bright stars. The Fourier spectrum of the combined 1994 and 1995 $r_B$ data and 1996

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1997AcA....47..365P



*I* data, presented in Fig. 2, shows a pattern characteristic for a single frequency. Unfortunately, the peaks at three alias frequencies of 0.1375, 1.1375, and 2.1375 $d^{-1}$ are almost equally high. Regardless of which alias frequency is used, the sine-curves fitted to the data by the least-squares method have the same standard deviation and the same semi-amplitude of about 17 mmag.

If the period of 7.273 d, corresponding to the lowest alias frequency, were the correct one, HDE 239886 could be classified as an $\alpha$ Cyg variable. This classification would be consistent with the star's MK type and the observed semi-amplitude.

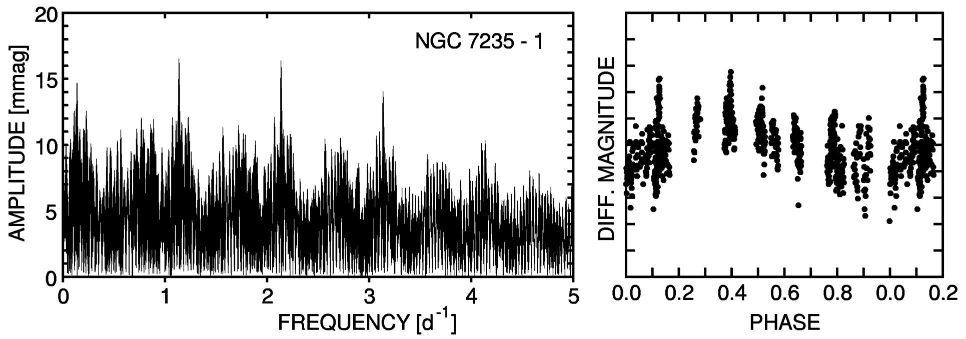


Fig. 2. Left: Fourier frequency spectrum of the B9 Iab supergiant NGC 7235-1 (HDE 239886) from the combined 1994–1995 $r_B$ and 1996 *I* data. Right: The same data phased with the period of $7.^d273$. The ordinate ticks in the right panel are spaced by 0.02 mag.

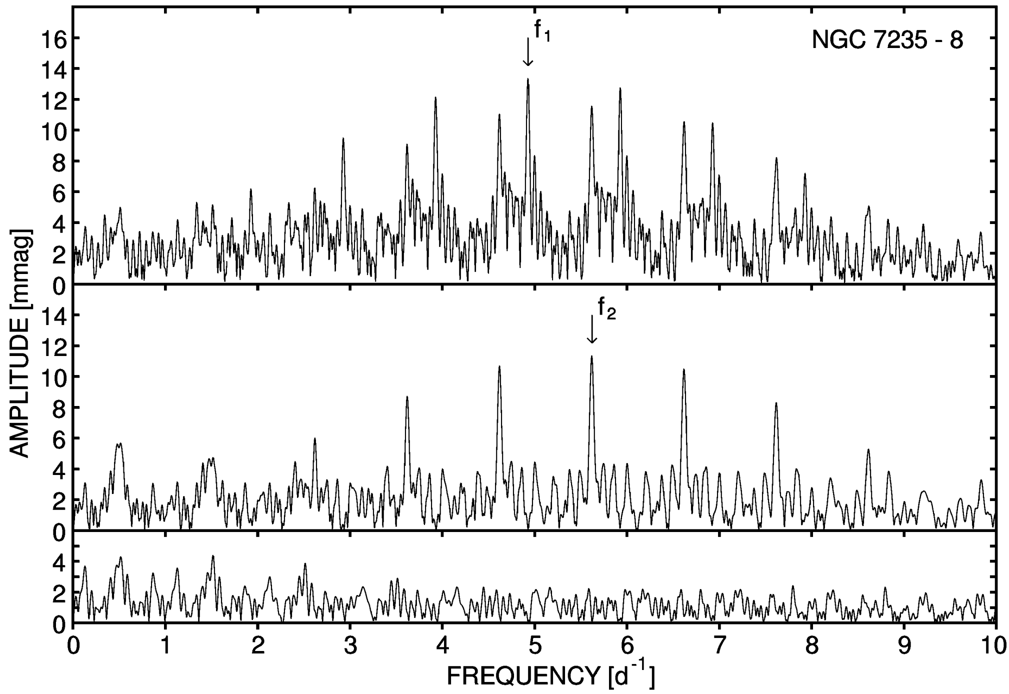


Fig. 3. Top: Fourier frequency spectra of the $\beta$ Cep variable NGC 7235-8 from the 1994 $r_B$ data. Middle: after prewhitening with $f_1 = 4.929$ $d^{-1}$. Bottom: after prewhitening with $f_1$ and $f_2 = 5.621$ $d^{-1}$.

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1997AcA....47..365P



**NGC 7235-8.** This is one of the brightest stars in the field and the only one which turned out to be a $\beta$ Cep variable. The Fourier spectra of the 1994 $r_B$ data, shown in Fig. 3, reveal two frequencies above the noise level: $f_1 = 4.929$ and $f_2 = 5.621$ d$^{-1}$. Both these frequencies occur in the periodograms of the other data sets as well. As can be seen from Fig. 3 (bottom), no significant peak in the spectrum can be seen after prewhitening with $f_1$ and $f_2$.

The best values of the periods, derived from all data, are $P_1 = 0.202890$ and $P_2 = 0^{\rm d}.177898$. Although these periods result in the smallest residuals and the largest amplitudes, they may be in error by 1 cycle per year because of the yearly gaps in the data. The $P_1$ and $P_2$ phase diagrams are shown in Fig. 4.

Table 2

Parameters of the fit of Eq. (1) to different data sets of the photometric data of NGC 7235-8. In this fit $P_1 = 0^{\rm d}.202890$, $P_2 = 0^{\rm d}.177898$, and $T_0$ = HJD 2449500. $N$ is the number of observations in a set. Numbers in parentheses denote the mean errors with the leading zeros omitted.

| Year(s) | N | $i$ | Filter | $A_0$ [mag] | $A_i$ [mmag] | $\phi_i$ [rad] | HJD of $T_{\max}$ |
|---|---|---|---|---|---|---|---|
| 1994 | 369 | 1 | $r_B$ | −1.4844(5) | 13.2(7) | 0.28(5) | 2449534.0256(17) |
| | | 2 | | | 11.2(7) | 4.52(6) | 2449533.9839(18) |
| 1995 | 266 | 1 | $r_B$ | −1.4821(5) | 10.4(8) | 0.12(8) | 2449885.2336(24) |
| | | 2 | | | 12.0(8) | 4.48(6) | 2449885.1558(18) |
| 1994+5 | 635 | 1 | $r_B$ | −1.4833(4) | 12.0(5) | 0.22(4) | 2449681.1227(14) |
| | | 2 | | | 11.6(5) | 4.50(5) | 2449681.1061(13) |
| 1996 | 188 | 1 | $V$ | 0.5000(5) | 14.7(7) | 0.17(4) | 2450240.2895(14) |
| | | 2 | | | 11.2(7) | 4.37(6) | 2450240.2432(16) |
| 1996 | 76 | 1 | $R$ | 0.5077(8) | 15.2(12) | 0.35(7) | 2450250.8339(22) |
| | | 2 | | | 12.9(12) | 4.53(8) | 2450250.9128(23) |
| 1996 | 201 | 1 | $I$ | 0.5076(4) | 14.0(6) | 0.30(4) | 2450243.3284(13) |
| | | 2 | | | 10.9(6) | 4.59(5) | 2450243.2612(15) |

In order to get the amplitudes and the initial phases of the two terms, we fitted the polynomial

$$A_0 + \sum_{i=1}^{2} A_i \sin\left[\frac{2\pi(t - T_0)}{P_i} + \phi_i\right] \qquad (1)$$

to our differential magnitudes by means of the method of least squares. The results are given in Table 2 for different sets of data.

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1997AcA....47..365P



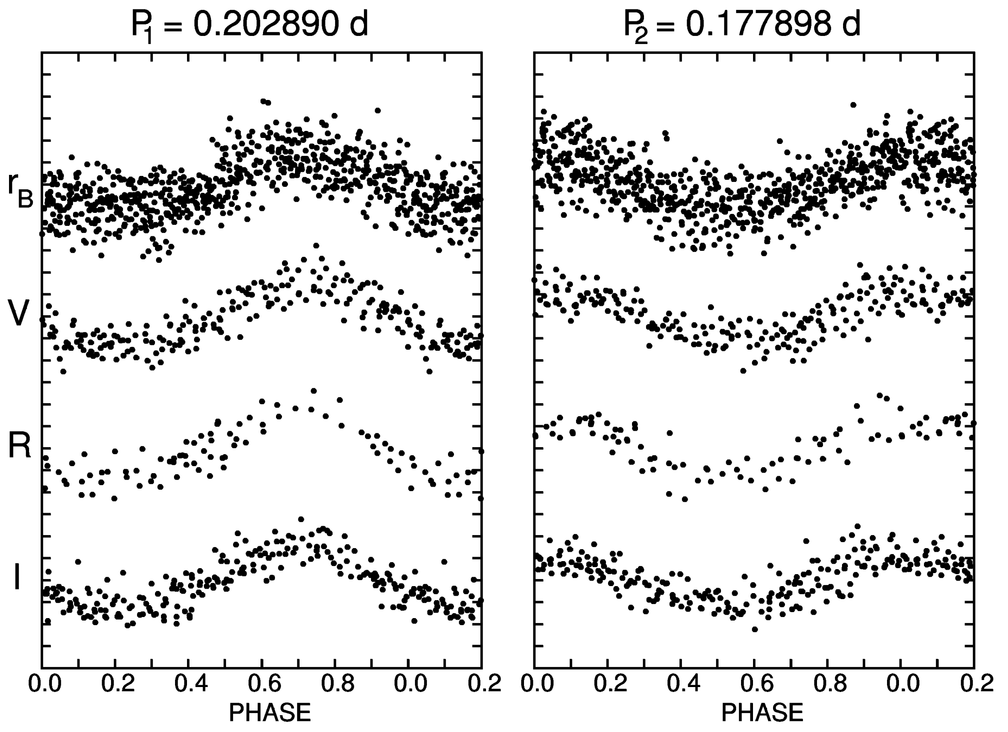


Fig. 4. The differential magnitudes of the $\beta$ Cep variable NGC 7235-8, phased with $P_1$ (left) and $P_2$. In either case, the data were prewhitened with the other period prior to phasing. Observations in $r_\mathrm{B}$ were made in 1994 and 1995, those in $V$, $R$ and $I$, in 1996. Phase zero corresponds to HJD 2449500. The ordinate tick marks are spaced by 0.01 mag.

NGC 7235-8 has been shown to be the cluster member by Hoag and Applequist (1965) and Becker (1965). As can be seen from the color-magnitude (C–M) diagrams in Fig. 10, it indeed lies on the cluster upper main sequence. The *UBV* color indices, dereddened by means of the $Q$-method (Johnson and Morgan 1953, Serkowski 1963) are $(B-V)_0 = -0.28$ and $(U-B)_0 = -0.96$. Such values are typical for a B1 star. We conclude that NGC 7235-8 is a $\beta$ Cep variable belonging to the cluster.

**NGC 7235-9.** In the C-M diagrams (see Fig. 10) this variable lies very close to NGC 7235-8 and is also a member. In the Fourier spectrum of the 1994 data, the highest peak appeared at $f = 1.16$ d$^{-1}$, corresponding to a period of $0^\mathrm{d}.862$. The period does not fit the 1995 data, but this is due to a large drop of brightness on HJD 2449866. In the spectrum of the 1996 data, the peak at frequency 1.16 d$^{-1}$ reappears. This type of behavior, as well as the length of the period and the amplitude, are characteristic for the $\lambda$ Eri variables, a subclass of variable Be stars (see Balona *et al.* 1992, Balona 1990, 1995). Combining the 1994 and 1996 data, we derived a refined value of the period, equal to $0^\mathrm{d}.86133$. The phase diagrams for the three sets of data, computed with this period, are shown in Fig. 5. Note that the amplitude varies from night to night, and that in 1994 a shallow minimum occurred at phase 0.55, where on most other occasions a maximum can be seen. Similar behavior has been observed in other $\lambda$ Eri variables by Balona *et al.* (1991).

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1997AcA....47..365P



No spectral classification is available for NGC 7235-9 and the star was never observed to show line emission. However, our H$\alpha$ photometry (see below, Section 5) clearly indicates the presence of emission at H$\alpha$. This strengthens our classification of NGC 7235-9 as a $\lambda$ Eri variable.

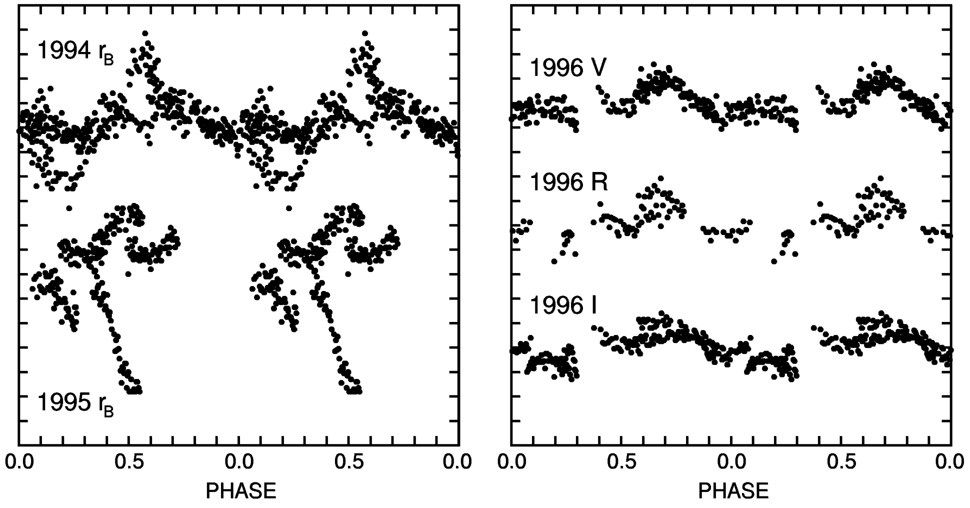


Fig. 5. The differential magnitudes of the $\lambda$ Eri variable NGC 7235-9, phased with the period of $P = 0\overset{\mathrm{d}}{.}86133$. Phase zero corresponds to HJD 2449500. The ordinate tick marks are spaced by 0.02 mag. Note the large drop in brightness on one night in 1995 (HJD 2449866) and the shallow minimum at phase 0.55 in 1994.

**NGC 7235-59.** In 1995 this star was brighter than in 1994 by about 0.1 mag, but it showed no variation over the one-month intervals of observations in either year. The *UBV* color indices (Becker 1965) imply $E(B-V) = 1.29$, if NGC 7235-59 is a B star – a value somewhat too large for NGC 7235. Therefore, it may be a background early-B star.

**NGC 7235-65.** This is another supergiant in our field. It has an MK type of K5 Ib according to Sowell (1987). However, its membership in NGC 7235 is doubtful (Becker 1965, Sowell 1987). A light variation of several tenths of a magnitude was detected by Sowell (1987) from his own observations and from a comparison of HJ and Becker's (1965) data. In 1994 and 1995 the star was constant to within 0.02 mag, but in 1996 variability of 0.05 mag could be seen in the three filters, $V$, $R$ and $I$. The variations are irregular.

**NGC 7235-66.** The *UBV* photometry of HJ implies that this is a B5 star belonging to the cluster. The amplitude spectrum of the combined 1994–1995 $r_B$ and 1996 $I$ data, plotted in the left panel of Fig. 6, shows the highest peak at $f = 0.5336$ d$^{-1}$. The corresponding period is $P = 1\overset{\mathrm{d}}{.}8741$. However, the $f + 1$ d$^{-1}$ and 1 d$^{-1}$ $-f$ aliases are almost equally high. Prewhitening with $f$ or either of the alias frequencies results in amplitude spectra with no peaks significantly exceeding the noise level. The star is thus singly periodic, but its true nature cannot be firmly established from our data. The minimum in the phase

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1997AcA....47..365P



diagram (Fig. 6, right panel) seems to be slightly narrower than the maximum. This suggests that the star may be an eclipsing or ellipsoidal variable. The possibility that NGC 7235-66 is a slowly pulsating B star (SPB, see Waelkens 1991) is unlikely in view of its single periodicity.

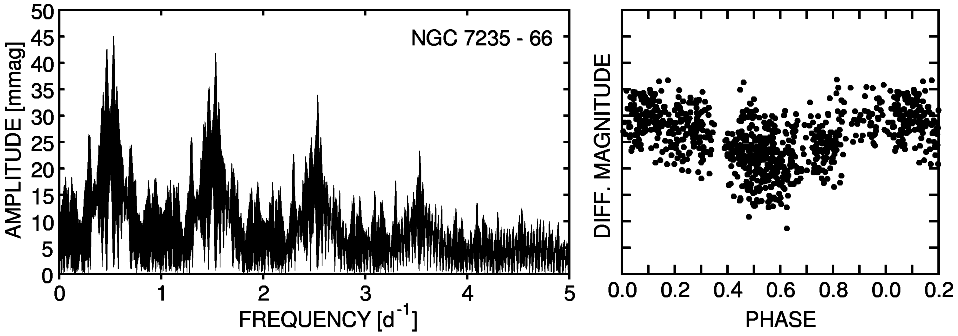


Fig. 6. Left: Fourier frequency spectrum of NGC 7235-66 from the combined 1994–1995 $r_B$ and 1996 $I$ data. Right: The same data phased with the period of $1\overset{d}{.}8741$; the ordinate tick marks are spaced by 0.02 mag.

**NGC 7235-142.** This is a red star with a small night-to-night variation. The range of variability was smaller than 0.1 mag in all filters in the three seasons. The variation is probably irregular, but if it were periodic, the period would be long. The star is too red to be a member of an open cluster as young as NGC 7235.

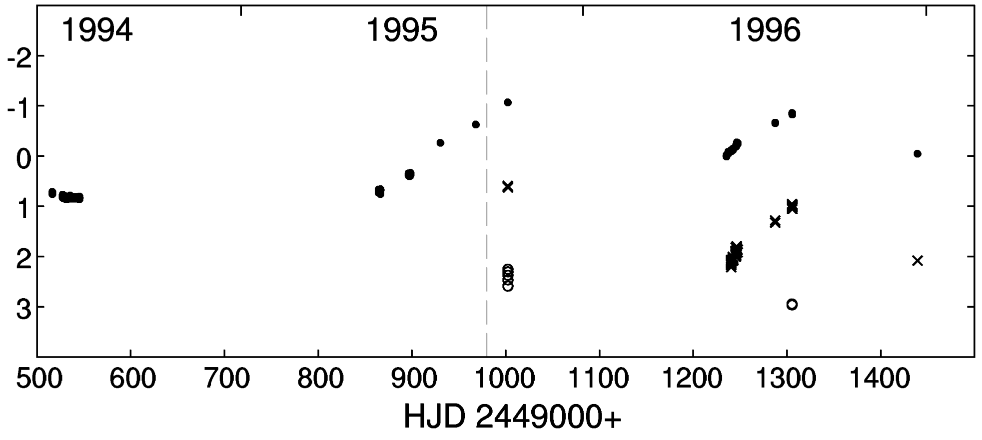


Fig. 7. Differential magnitudes of the Mira-type variable NGC 7235-175, plotted as a function of time. The vertical dashed line separates the $r_B$-filter observations from those made with the other filters, $V$ (open circles), $R$ (crosses), and $I$ (filled circles). The ordinate is expressed in mag.

**NGC 7235-175.** This is the reddest star in our field. It also shows the largest light variation. As can be seen from Fig. 7, where differential magnitudes of NGC 7235-175 are plotted as a function of time, the amplitude is larger in $R$ than in $I$; there is a change of the $R-I$ color index by about 0.4 mag between September 1995 and May 1996. Thus, the star becomes bluer with increasing brightness, a behavior characteristic of Mira-type variables. Because of the large gaps in the

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1997AcA....47..365P



data the period cannot be reliably determined. Nevertheless, we conclude that NGC 7235-175 is a Mira-type star.

**NGC 7235-191**. This star turned out to be a W UMa eclipsing binary with an orbital period of about $0\overset{d}{.}280$, one of the shortest known for this type of variable. The phase diagrams, shown in Fig. 8, reveal minima of slightly unequal depth.

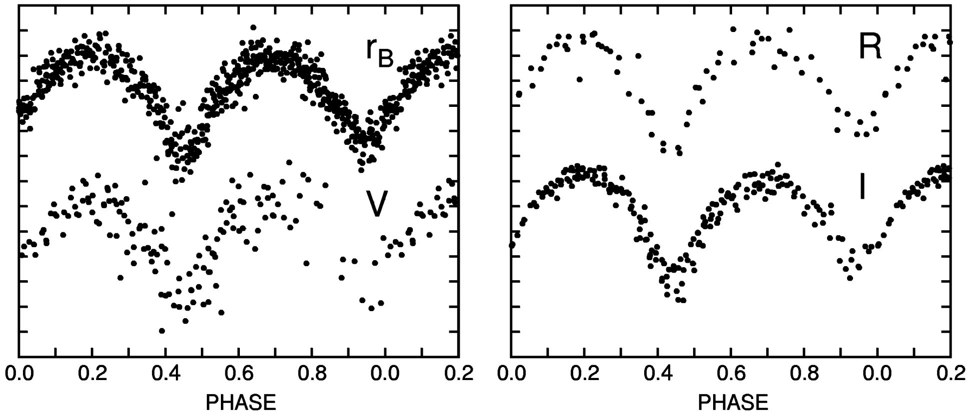


Fig. 8. Differential magnitudes of the eclipsing binary NGC 7235-191, phased with $P = 0\overset{d}{.}2800284$. The ordinate tick marks are spaced by 0.1 mag.

In order to determine the times of primary minima we generated a synthetic light-curve and then fitted it to each night's observations separately. In this way we could obtain the time of a primary minimum even if it was not actually observed. The times of primary minimum are given in Table 3.

Using the times of the primary minima from Table 3 with weights inversely proportional to their mean errors, we derived the following ephemeris:

$$\text{Min } I = \text{HJD } 2449516.3664(7) + 0.2800284(4)\, E\,, \tag{2}$$

where $E$ is the number of elapsed cycles, and the numbers in parentheses are the mean errors without the leading zeros.

W UMa variables are known to satisfy an empirical period-color relation (Eggen 1961, Ruciński 1992). According to this relation, NGC 7235-191 should have $(B-V)_0 \approx 0.83$. Comparing this number with $B-V = 1.31$ from Table 4[1], we see that the color excess of the star is much smaller than would be the case if it were a member of NGC 7235. In addition, the distance modulus of NGC 7235-191 can be estimated from the $M_V(\log P, B-V)$ calibration of Ruciński (1994) as $(m-M)_V \approx 10.7$. This is well outside the range of 12.5 to 13.1, mentioned in the Introduction. Clearly, NGC 7235-191 is a foreground object.

[1] Table 4 is available only in electronic form via anonymous ftp to 148.81.8.1, see cover page for details.

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1997AcA....47..365P



Table 3

The primary light minima of NGC 7235-191. Numbers in parentheses are the mean errors, expressed in units of $0\overset{d}{.}0001$

| HJD of $T_{min}$ (2449000+) | Filter | $E$ | $O-C$ [days] | HJD of $T_{min}$ (2449000+) | Filter | $E$ | $O-C$ [days] |
|---|---|---|---|---|---|---|---|
| 516.3669(16) | $r_B$ | 0 | +.0005 | 898.3247(14) | $r_B$ | 1364 | −.0004 |
| 527.5650(22) | $r_B$ | 40 | +.0025 | 1235.4777(08) | $I$ | 2568 | −.0016 |
| 528.4068(12) | $r_B$ | 43 | +.0008 | 1235.4787(21) | $V$ | 2568 | −.0006 |
| 529.5280(15) | $r_B$ | 47 | +.0003 | 1237.4389(10) | $I$ | 2575 | −.0006 |
| 530.3680(14) | $r_B$ | 50 | +.0002 | 1237.4445(32) | $V$ | 2575 | +.0050 |
| 531.4883(15) | $r_B$ | 54 | +.0004 | 1240.5173(20) | $V$ | 2586 | −.0025 |
| 532.3234(19) | $r_B$ | 57 | −.0046 | 1240.5177(14) | $R$ | 2586 | −.0021 |
| 535.4108(13) | $r_B$ | 68 | +.0025 | 1240.5194(10) | $I$ | 2586 | −.0004 |
| 536.5281(10) | $r_B$ | 72 | −.0003 | 1242.4718(38) | $R$ | 2593 | −.0082 |
| 537.3685(11) | $r_B$ | 75 | .0000 | 1242.4801(14) | $I$ | 2593 | +.0001 |
| 540.4499(19) | $r_B$ | 86 | +.0011 | 1242.4865(33) | $V$ | 2593 | +.0065 |
| 544.3663(15) | $r_B$ | 100 | −.0029 | 1245.5600(20) | $R$ | 2604 | −.0004 |
| 545.4920(11) | $r_B$ | 104 | +.0026 | 1245.5623(08) | $I$ | 2604 | +.0019 |
| 864.4439(12) | $r_B$ | 1243 | +.0022 | 1245.5623(30) | $V$ | 2604 | +.0019 |
| 866.4043(12) | $r_B$ | 1250 | +.0024 | 1246.3992(18) | $I$ | 2607 | −.0012 |
| 896.3662(09) | $r_B$ | 1357 | +.0013 | 1246.3995(59) | $V$ | 2607 | −.0009 |
| 897.4859(10) | $r_B$ | 1361 | +.0008 | 1246.4003(16) | $R$ | 2607 | −.0001 |

## 4. The *BVRI* Photometry

### 4.1. Standardization

The search frames were also used for deriving instrumental $V$, $R$ and $I$ magnitudes. The procedure consisted in forming differential magnitudes with respect to NGC 7235-5 and then applying second-order (that is, color dependent) extinction corrections. The instrumental $B$ magnitudes were obtained in a similar way from a single long-exposure frame, taken on the night of December 21/22, 1996.

From observations of Landolt's (1992) standard stars, that were also carried out on December 21/22, 1996, we derived the following transformation equations to the standard $BV(RI)_C$ system of Johnson, Kron and Cousins:

$$I = i + 0.007 \times (v - i) + 10.512\,, \tag{3}$$

$$B - V = 0.997 \times (b - v) + 0.678\,, \tag{4}$$

$$V - I = 0.947 \times (v - i) + 0.881\,, \tag{5}$$

$$V - R = 0.957 \times (v - r) + 0.422\,, \tag{6}$$

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1997AcA....47..365P



where $b$, $v$, $r$, and $i$ denote the instrumental magnitudes. These equations were then used to compute the $I$ magnitude and the $B-V$, $V-I$, and $V-R$ color indices. The results are given in Table 4. The limiting magnitudes of our photometry are 17.5, 17.5, 17.0 and 16.5 in $B$, $V$, $R$ and $I$, respectively.

Since the instrumental $v$, $r$, and $i$ magnitudes were determined as a mean from all differential magnitudes, the internal accuracy of our instrumental photometry is very high. For the faintest stars we present in Table 4, it is of the order of 0.02, 0.03, and 0.01 mag for $v$, $r$, and $i$, respectively, whereas for well separated bright stars it amounts to 2, 1, and 0.5 mmag. This is not the case for the $b$ photometry, which is much less accurate because it was obtained from a single frame. The accuracy of this photometry ranges from 4 mmag for the brightest stars to 0.2 mag for the faintest.

The standardization introduces additional errors; they are of the order of 0.02 mag for the cluster main sequence and at least twice as large for the reddest stars.

### 4.2. *Comparison with Previous Work*

As we already mentioned in the Introduction, *UBV* photometry of NGC 7235 has been previously published by HJ and Becker (1965). A comparison of our $B-V$ color indices and $V$ magnitudes for all stars in common with these two data sets is shown in Fig. 9.

The color index differences, $\Delta(B-V)$, plotted in the upper panel of Fig. 9, show considerable scatter, especially for the reddest stars, but for the cluster main sequence stars $\Delta(B-V)$ is within the expected errors of the photometries we compare. On the other hand, the $V$ magnitude differences (Fig. 9, lower panel) show two systematic effects. The first effect consists in a number of stars having large positive values of $\Delta V$. This effect was also present in NGC 7128 (see Paper I) and is due to crowded stars, resolved by the PSF fitting technique we used, but unresolved by HJ and Becker (1965). The second effect is a systematic trend towards positive $\Delta V$ for stars fainter than $V \approx 15$ mag. The effect arises probably from incorrect extrapolation of the photographic magnitudes beyond the range covered by photoelectric standards. It is interesting to note that in NGC 7128 a similar effect was observed (see Fig. 11 of Paper I), but with the faint photographic magnitudes deviating in the opposite direction than in Fig. 9.

### 4.3. *The Color-Magnitude Diagrams*

Two color-magnitude diagrams for NGC 7235 are displayed in Fig. 10. The variable stars are shown with open squares; they are also labeled "Var" in the last column of Table 4. Stars which are almost certainly non-members are plotted as crosses. These stars are labeled "NM" in the last column of Table 4.

There are only two stars in the C–M diagrams of NGC 7235 which lie close to the $\beta$ Cep star, NGC 7235-8. These are NGC 7235-9, the $\lambda$ Eri variable we discovered, and NGC 7235-183. The latter, however, has the $V-I$ color index

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1997AcA....47..365P



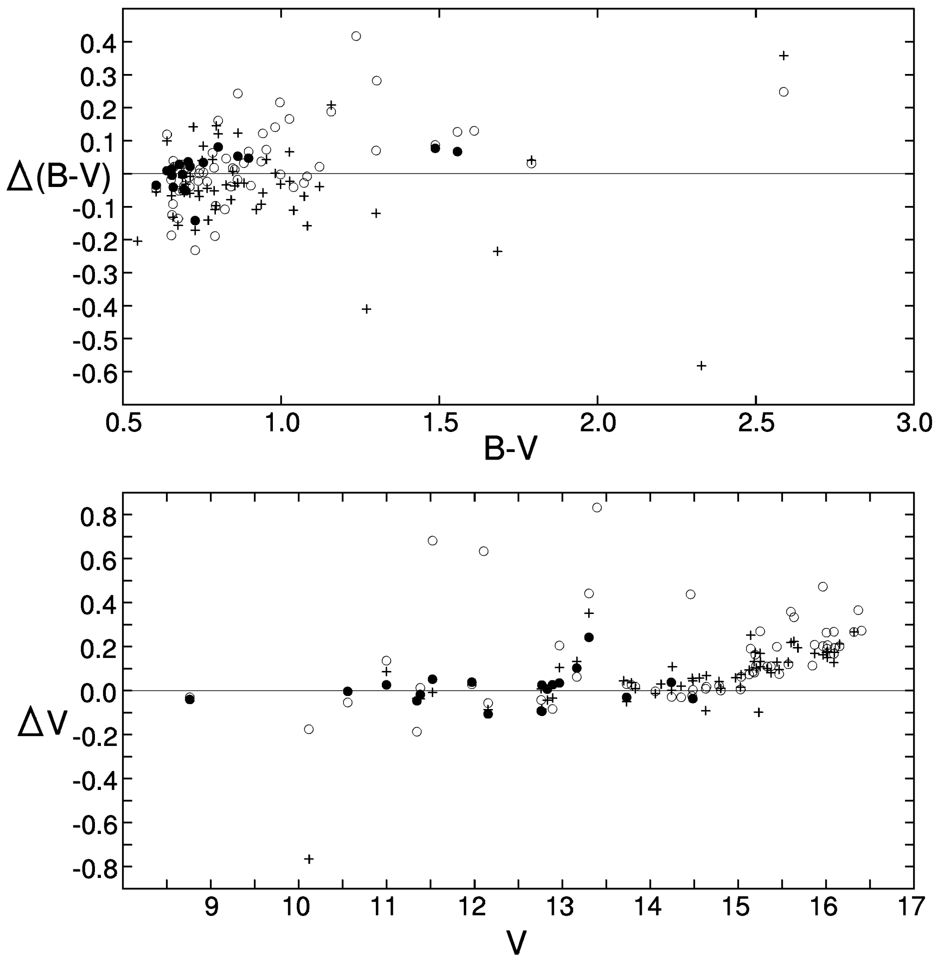


Fig. 9. The differences, $\Delta(B-V)$ (upper panel), and $\Delta V$ (lower panel), in the sense ours *minus* HJ photoelectric (filled circles), HJ photographic (open circles), and Becker (1965) photographic (plus signs). The differences are expressed in mag. Note that $\Delta(B-V)$ are plotted as a function of $B-V$, while $\Delta V$, as a function of $V$.

considerably bluer than other stars of similar magnitude and therefore is probably a foreground object.

## 5. The H$\alpha$ Photometry

Information about the presence of Be stars would be important in our study of the stellar content of young open clusters. Since the strongest emission in the visual part of the spectrum of a Be star occurs in the hydrogen H$\alpha$ line, observations of this line are most suitable for the purpose. With this in mind, we purchased a pair of interference filters, both centered at H$\alpha$, but differing in bandwith. The first filter, narrow, has full width at half maximum (FWHM) equal to 3.0 nm, whereas the second one, wide, has FWHM equal to 20 nm. As was already shown by Goderya and Schmidt (1994), such filters are indeed suitable for finding emission-line stars.

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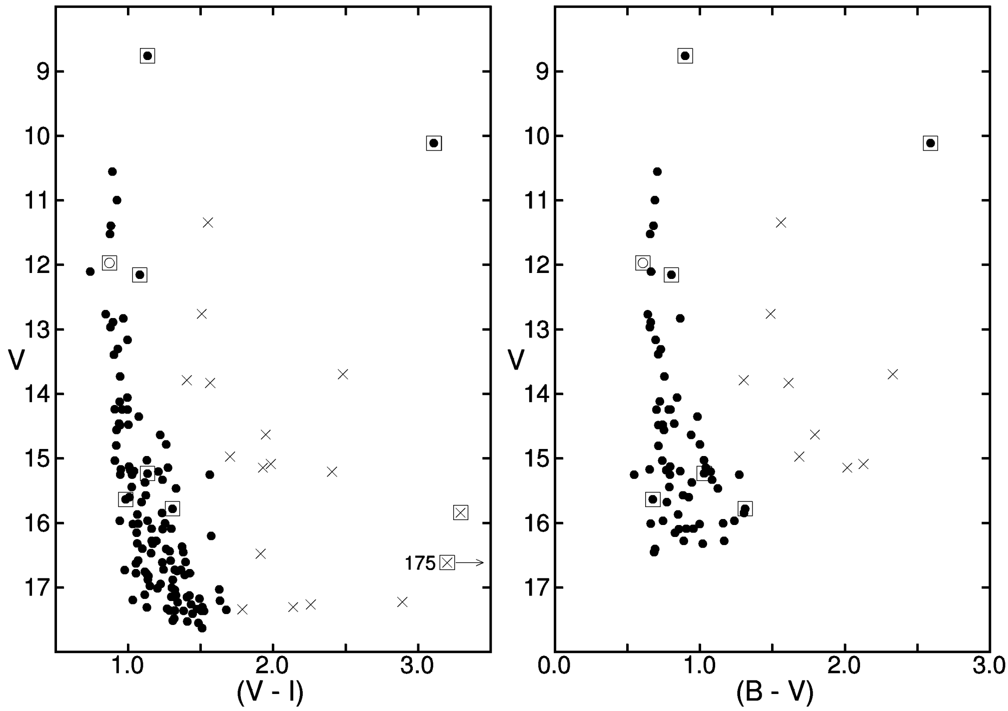


Fig. 10. Two C-M diagrams for NGC 7235. The red non-members are plotted as crosses, whereas the $\beta$ Cep star, NGC 7235-8 is plotted as an open circle. Symbols denoting variable stars are enclosed in large open squares. In the left panel, NGC 7235-175 (labeled) has $V-I=6.50$.

Following the well-known example of the photometric $\beta$ index, we define an $\alpha$ index as the difference between the magnitudes measured with the narrow filter, $N$, and the wide one, $W$:

$$\alpha = N - W + C. \tag{7}$$

The index is a function of the equivalent width of the H$\alpha$ line, and is therefore a good measure of emission at this line. The constant $C$ is related to the ratio of exposure times in the two filters and to the difference in zero points between the frames. In practice, the narrow filter exposure is sandwiched between two wide filter ones. Then, the observations with the wide filter are interpolated to the mid-time of the narrow filter exposure. The zero points of the $N$ and $W$ magnitude scales are calculated separately for each frame from aperture photometry of selected bright stars.

The observations of NGC 7235 with the H$\alpha$ filters were made on the night of August 8/9, 1996. They consisted of two 600-s wide-filter exposures, separated by a single 2000-s narrow-filter frame. The resulting $\alpha$ indices are listed in Table 4 and are plotted in Fig. 11. Despite the small width of the narrow filter, the $\alpha$ index could be derived for about 60 brightest stars in the field. The limiting magnitude of $\alpha$ corresponds to $V \approx 15.5$ for the cluster main sequence stars.

It is obvious from Eq. (7) that objects with emission at H$\alpha$ should have lower $\alpha$ index than normal stars. Thus, strong emission at H$\alpha$ can explain the position

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1997AcA....47..365P



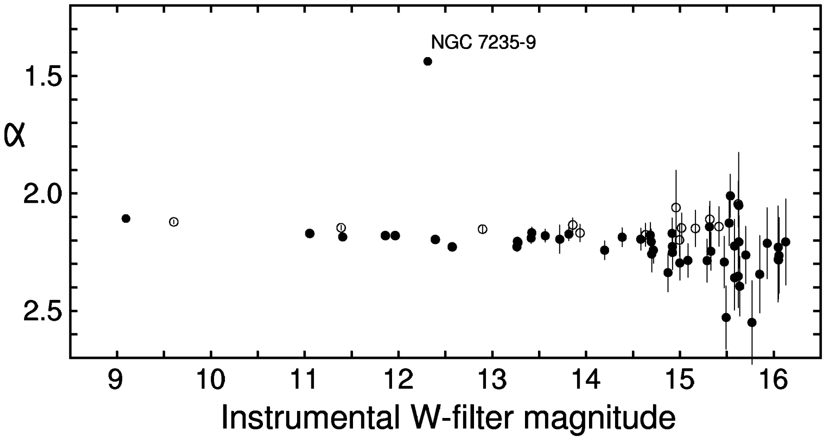


Fig. 11. The $\alpha$ index for the brightest stars in NGC 7235. Red stars are shown as open circles.

of NGC 7235-9 in Fig. 11. This fact was already used in Section 3 to strengthen our classification of the star as a $\lambda$ Eri variable.

## 6. Summary

In a $4' \times 6'$ field, covering NGC 7235, we found nine variable stars. Four of them we could unambiguously classify: NGC 7235-8 as a $\beta$ Cep variable, NGC 7235-9 as a $\lambda$ Eri variable, NGC 7235-175 as a Mira, and NGC 7235-191 as a W UMa eclipsing binary. For two stars, NGC 7235-1 and 66, the variability classification is uncertain; the first is probably an $\alpha$ Cyg variable, while the second may be an eclipsing variable with a period of $1\overset{\mathrm{d}}{.}8741$. The remaining three variable stars, NGC 7235-59, 65 and 142, could not be classified because of insufficient data. The $\beta$ Cep star, the $\lambda$ Eri variable, the candidate $\alpha$ Cyg variable and the probable eclipsing binary are members of the cluster.

We also carried out observations which enabled us to transform our instrumental magnitudes to the standard $BV(RI)_{\mathrm{C}}$ system of Johnson, Kron and Cousins. For 193 stars in our field we provide new $I$ magnitudes and $R-I$ color indices; for 141 of them, the $V-I$ color indices; for 76, the $B-V$ color indices. In addition, we defined an $\alpha$ index which is a measure of the strength of the H$\alpha$ line. We give the $\alpha$ index for 64 brightest stars in our field. For NGC 7235-9, the $\alpha$ index reveals strong emission at H$\alpha$; this helped to classify the star as a $\lambda$ Eri variable.

The $\beta$ Cep variable, NGC 7235-8, is an average representative of its class. The dereddened color indices, mentioned in Section 3, place it in the middle of the $\beta$ Cep sequence (see, for example, Sterken and Jerzykiewicz 1993). The two periods are also typical.

We found no SPB stars in NGC 7235. Of the two variables with the color indices in the mid-B range, that is, NGC 7235-59 and 65, neither is a good candidate because the first shows only long-term variations, while the second is singly periodic and may be an eclipsing binary. A similar result was obtained for NGC 7128 in Paper I.

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1997AcA....47..365P



In NGC 7128, the only variable of unknown type in the mid-B range turned out to be singly periodic, and therefore not likely to be a $g$-mode pulsator of the SPB type.

Finally, finding a foreground W UMa-type binary, NGC 7235-191, projected on NGC 7235 is not surprising, because – as was pointed out by Ruciński (1994) – the probability of contamination of distant open clusters by objects of this type is quite high.

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