A CCD Search for Variable Stars of Spectral Type B in the Northern Hemisphere Open Clusters. V. NGC 2169

by

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ABSTRACT

We present results of a search for variable stars in the field of the young open cluster NGC 2169. The General Catalogue of Variable Stars (GCVS, http://www.sai.msu.su/groups/cluster/gcvs/) lists four variable stars in the field we observed, viz., two β Cep stars, V 916 and V 917 Ori, an α2 CVn variable, V 1356 Ori, and an RRc variable, V 1154 Ori. We find V 916 and V 1154 Ori to be constant in light. We confirm the variability of V 917 Ori, but not the period given in GCVS. For the chemically peculiar A0 V Si star V 1356 Ori we definitely establish the period of 1.565 d, thus settling the uncertainty persisting in the literature since the star was discovered to be variable. In addition, we find two other stars to be variable in light. Both show irregular variations.

For V 917 Ori, one of the two GCVS β Cep variables, we determine a period of 0.267 d (frequency 3.7477 d−1). However, prewhitening with this period leaves a significant amount of the star’s light-variation unaccounted for. Since the star shows emission at Hα, we hypothesize that the unaccounted for variation is caused by an erratic, Be-type activity. As to the periodic term, we consider three hypotheses: (1) β Cep-type pulsation, (2) rotational modulation of the λ Eri type, and (3) ellipsoidal variation due to distorted primary component in a close binary system. After deriving the star’s effective temperature from Strömgren indices and the luminosity from the distance modulus of the cluster, we show that while the third hypothesis is untenable, the first two should be retained. However, neither is entirely satisfactory.

For a number of stars we provide the V magnitudes. For 14 brightest stars in our field we also obtain the photometric α-index, a measure of the Hα equivalent width. From the α index, we detect mild emission at Hα in two stars, V 917 Ori and NGC 2169-8.

Key words: Stars: early-type – Stars: oscillations – open clusters and associations: individual: NGC 2169

1. Introduction

This is the fifth paper of the series containing results of our search for B-type variable stars in young open clusters of the Northern Hemisphere. In the preceding papers we presented results for the following open clusters: NGC 7128
(Jerzykiewicz et al. 1996, hereafter Paper I), NGC 7235 (Pigulski et al. 1997, Paper II), NGC 6823 (Pigulski et al. 2000, Paper III), and NGC 663 (Pigulski et al. 2001, Paper IV). Altogether we discovered some 50 variables. A recent summary of our project has been provided by Pigulski et al. (2002). In what follows we report the results for another young open cluster, NGC 2169. Some of these results have been already presented by Kopacki et al. (2003).

NGC 2169 (C 0605+139, OCl 481) is a sparsely populated, young open cluster in Orion. According to Ruprecht (1966), the Trumpler type is I 3p.

An investigation of the intrinsic properties of NGC 2169 by means of $uvby$ and $H\beta$ photometry, MK spectral types and radial velocities of the 18 brightest stars has been carried out by Perry et al. (1978). According to these authors, the mean reddening, $E(B-V)$, is equal to $0.20 \pm 0.01$ mag, the distance modulus, $V_0 - M_V$, is equal to $10.2 \pm 0.1$ mag, and the upper limit to the age, $\tau$, is equal to $2.3 \times 10^7$ yr. Subsequent $uvby\beta$ studies (Delgado et al. 1992, Peña and Peniche 1994) are in acceptable agreement with Perry et al. (1978). In particular, the distance modulus is equal to 10.0 mag (no standard deviation given) according to Delgado et al. (1992), and $9.7 \pm 0.3$ mag according to Peña and Peniche (1994). A straight mean of the three above-mentioned values of $V_0 - M_V$ amounts to $10.0 \pm 0.3$ mag (estimated standard error).

NGC 2169 has been included in a comparison of cluster sequences with theoretical isochrones of models with mass loss by Mermilliod and Maeder (1986). These authors use a distance modulus of 10.65 mag. In Mermilliod’s WEBDA database (http://obswww.unige.ch/webda) one finds the cluster’s distance equal to 1052 pc and $V_0 - M_V = 10.75$ mag. Note that this value does not differ much from $V_0 - M_V$ used by Mermilliod and Maeder (1986), but is inconsistent with the distance of 1052 pc; the latter value yields $V_0 - M_V = 10.1$ mag, close to the mean distance modulus derived in the preceding paragraph. In view of this inconsistency, WEBDA’s $V_0 - M_V = 10.75$ mag should be used with caution.

2. Observations and Reductions

Our observations of NGC 2169 were carried out at the Białków Observatory of the Wrocław University on 16 nights in the interval from January 5 to April 3, 2002. We used the equipment described in Papers I and II, viz., a 60-cm reflecting telescope with a $384 \times 576$ CCD camera, mounted in the Cassegrain focus, an autoguider, a set of $BV(RI)_C$ filters, and a pair $H\alpha$ interference-filters, narrow (having FWHM equal to 3 nm) and wide (FWHM equal to 20 nm). Most frames, nearly 3300, were taken through the $V$ filter; on 11 nights some 160 frames were taken through the $I_C$ filter. The $H\alpha$ filters were used on one night, February 2/3, 2002. On this night, six frames were taken through the wide $H\alpha$ filter, and three, through the narrow $H\alpha$ filter. The integration time was equal to 30 s for the $V$- and $I_C$-filter frames; in case of the $H\alpha$ filters, the integration time was equal to 90 s and
300 s for the wide and narrow filter, respectively. All frames were calibrated in the same way as in Paper I and then reduced by means of Stetson’s (1987) DAOPHOT II package.

Fig. 1. A view of the field of NGC 2169 we observed. North is up, East to the left. The field covers an area of $4' \times 6'$. The two encircled symbols represent stars for which we detected emission at Hα. The numbering system is explained in the text.

Fig. 1 shows the $4' \times 6'$ field we observed. There are 45 stars in Fig. 1, numbered from 1 to 78; the missing numbers are outside the field. The numbers between 1 and 25 are from the photoelectric sequence of Hoag et al. (1961), those greater than 25 but not exceeding 59 are from the WEBDA extension of this sequence, and finally, the consecutive numbers from 60 to 78 were assigned by us.

3. Variable Stars

Using DAOPHOT magnitudes, we formed differential magnitudes for all stars in the field. The differential $V$ magnitudes were then analyzed for variability. The analysis included inspecting light-curves by eye and computing least-squares (LS) power or amplitude spectra in the frequency range from $0 \text{ d}^{-1}$ to $30 \text{ d}^{-1}$. As in our earlier papers, the LS spectra were computed by means of a slightly modified version of the well-known method of Lomb (1976). The modification consisted in (1) using a floating mean in the LS fit, and (2) giving each differential magnitude a weight inversely proportional to $\sigma^2$, where $\sigma$ is the standard deviation of the differ-
ential magnitude derived from DAO\textsc{hot}'s standard deviations of the magnitudes, and then multiplying each equation of condition by a square root of the weight. We mention the obvious modification (1) because it has been recently heralded as a major improvement by Cumming \textit{et al.} (1999).

We shall now discuss the four stars that have been found to be variable in light by others, and two new variables, discovered in this work.

**NGC 2169-2=HDE 252214=V 916 Ori.** From 40 photoelectric measurements in $B$, 25 in $U$, and 24 in $V$, Hill (1967) found the star to be variable, derived a period of 0.39912 d (frequency 2.5055 d$^{-1}$) and the amplitudes (half ranges) of 9 mmag and 8 mmag in $B$ and $U$, respectively (no $V$ amplitude was given). On the strength of these results, Hill (1967) classified the star as a $\beta$ Cep variable. However, Delgado \textit{et al.} (1992), from 42 uvby observations obtained on two nights, concluded that NGC 2169-2 was constant in light.

Our 3270 differential $V$ magnitudes of NGC 2169-2, computed with NGC 2169-11 and 15 as comparison stars, show little variation. As can be seen from Fig. 2 (top), in the LS power spectrum there is some power at low frequencies, with the highest peak occurring at 0.106 d$^{-1}$. In the LS amplitude spectrum (Fig. 2, middle), the amplitude at this frequency is equal to 10 mmag, while maximum amplitudes around Hill’s (1967) frequency of 2.5055 d$^{-1}$ amount to 6 mmag. After prewhitening with the frequency of 0.106 d$^{-1}$, the amplitudes at frequencies higher than 2 d$^{-1}$ drop to below 5 mmag (Fig. 2, bottom). We conclude that (1) the period of 0.39912 d, derived by Hill (1967), is spurious, and (2) the star exhibits no $\beta$ Cep-type light-variations with an amplitude exceeding 5 mmag in $V$.

The low-frequency power seen in Fig. 2 (top), and the amplitudes at low frequencies in Fig. 2 (middle), including the peak at 0.106 d$^{-1}$, are probably caused by the circumstance that central pixels in the image of the star were saturated on the CCD frames taken under conditions of good seeing. Since DAO\textsc{hot} ignores saturated pixels, the magnitudes derived from such frames would be less accurate than those from images without saturated pixels. This introduces scatter without appreciably changing the DAO\textsc{hot}'s standard deviations of the individual magnitudes. Consequently, the less accurate magnitudes enter the LS analysis with high weight, so that the scatter translates into increased power at low frequencies. Some credibility to this reasoning is lent by the fact that NGC 2169-5 and 6, which were never saturated on our frames, do not suffer from excessive low-frequency noise (see Fig. 3 middle and bottom).

**NGC 2169-5=HDE 252248=V 917 Ori.** This star was also announced by Hill (1967) to be a $\beta$ Cep variable. From similar data as in the former case, Hill (1967) derived a period of 0.4033 d (frequency 2.4795 d$^{-1}$) and the amplitudes equal to 11, 16, and 20 mmag in $B$, $V$, and $U$, respectively. In addition, Hill (1967) found that the star is a fast rotator, having $v \sin i$ of at least 320 km/s.

Delgado \textit{et al.} (1992) have confirmed the variability, but not the period. From 42 uvby observations obtained on two nights, they suggest a period of about 0.3 d
and hypothesize that V 917 Ori is “a Be-type star, showing variations due to rotation,” although the only evidence of line-emission they had was the star’s position in the $c_0 - \beta$ diagram.

Using NGC 2169-6 and 14 as comparison stars, we formed 3270 differential $V$ magnitudes of V 917 Ori. As can be seen from Fig. 3 (top), the three highest peaks in the power spectrum of these data occur at the frequencies equal to $3.7477 \text{ d}^{-1}$, $3.6523 \text{ d}^{-1}$ and $4.6548 \text{ d}^{-1}$. The $V$ amplitude of a sine-curve LS fit amounts to 10.5 mmag, 10.1 mmag and 9.9 mmag, for the first, the second and the third frequency, respectively. On the other hand, the power spectrum of the differential magnitudes “NGC 2169-14 minus 6” shows only low-amplitude noise (Fig. 3, bottom). Thus, V 917 Ori is undoubtedly variable. However, our data are insuf-

![Fig. 2. The LS spectra of V 916 Ori, computed from the differential $V$ magnitudes. Top: the power spectrum; note that the vertical axis has been truncated at 0.3. Middle: the amplitude spectrum. Bottom: the amplitude spectrum of the data prewhitened with $0.106 \text{ d}^{-1}$, the frequency of the highest peak in the power spectrum. Spikes in the amplitude spectra at 0.5 and 1 \text{ d}^{-1} are artefacts.](image-url)
A. A.

sufficient to decide which of the above-mentioned three frequencies is more nearly correct. Fortunately, Delgado’s et al. (1992) observations can be used to eliminate the second and third frequency. Indeed, the amplitude of a sine-curve LS fit to these data (the “mean normalized differences” in their Fig. 16) is equal to insignificant $7.3 \pm 3.0$ mmag and $5.7 \pm 2.9$ mmag for the second and third frequency, as opposed to highly significant $16.6 \pm 2.0$ mmag for the first frequency.

![Power Spectrum](image)

Fig. 3. The LS power spectra of V 917 Ori and the comparison stars, NGC 2169-6 and 14. Top: the power spectrum of the differential \( V \) magnitudes “V 917 Ori minus the mean of NGC 2169-6 and 14.” Middle: after prewhitening with $3.7477$ d\(^{-1}\). Bottom: the power spectrum of the differential \( V \) magnitudes “NGC 2169-14 minus 6.”

Prewhitening the differential \( V \) magnitudes “V 917 Ori minus the mean of NGC 2169-6 and 14” with the frequency of $3.7477$ d\(^{-1}\) results in a noisy power spectrum without a dominant peak (see the middle panel of Fig. 3). Clearly, the star’s variation cannot be accounted for by a single sine-wave.

The same conclusion follows from the phase diagrams shown in Fig. 4. One can indeed see that the scatter of the variable star’s differential magnitudes around the $3.7477$ d\(^{-1}\) light-curve (upper panel) is appreciably larger than the scatter of the differential magnitudes of the comparison stars (lower panel). This impression is confirmed by the following numbers: the standard deviation of the $3.7477$ d\(^{-1}\)
sine-curve LS fit to the variable star data is equal to 5.6 mmag, while the standard deviation of the differential magnitude (of unit weight) between the comparison stars is equal to 3.4 mmag.

Fig. 4. The phase diagrams of the differential \( V \) magnitudes “V 917 Ori minus the mean of NGC 2169-6 and 14” (upper panel), and the differential \( V \) magnitudes “NGC 2169-14 minus 6” (lower panel), computed with the frequency equal to 3.7477 d \(^{-1}\) and the initial epoch HJD 2452270.000.

The 3.7477 d \(^{-1}\) term in the light variation of V 917 Ori may be caused by (1) pulsation, (2) rotation (as suggested by Delgado et al. 1992), or (3) proximity effects in a close binary system. In case (1), the star would be a \( \beta \) Cep variable (as suggested by Hill 1967); in case (2), it should be referred to as a \( \lambda \) Eri variable (Balona 1990, 1995); finally, in case (3), it would be classified as an ellipsoidal variable.

In order to examine these hypotheses, let us derive the star’s effective temperature and luminosity. As far as estimating the effective temperature is concerned, the MK types available in the literature are useless because they range from B2 V (Hoag and Applequist 1965) to B6 V (Perry et al. 1978), with B3 Vn (Abt 1977) and B5 V (van Rensbergen et al. 1978) in between, and it is difficult to say which of them, if any, is the reliable one. The \( uvby \) photometry fares much better in this respect. In the three series of the \( uvby \) observations mentioned in the Introduction, the \( b - y \) and \( c_1 \) indices show ranges of about 0.02 mag. Using these data one gets \( c_0 = 0.161 \pm 0.005 \) mag, where the standard deviation is dominated by the (estimated) uncertainty in the reddening slope \( E(c_1)/E(b - y) \). For luminosity class V, this value of \( c_0 \) corresponds to spectral type between B1.5 and B2 (see Table II of
Crawford 1978), and the effective temperature equal to 20 170 K, the last number being the mean of two values, obtained by means of two \( c_0 - T_{\text{eff}} \) calibrations, that of Shobbrook (1979), and that of Sterken and Jerzykiewicz (1980), both based on the empirical \( T_{\text{eff}} \) scale of Code et al. (1976). The standard deviation of this \( T_{\text{eff}} \) value is equal to about 900 K, with the uncertainty of the Code’s et al. (1976) scale contributing 90%, and the standard deviation of \( c_0 \) and the difference between the photometric calibrations, the remaining 10%.

For deriving the absolute magnitude of V 917 Ori we shall use the mean distance modulus of the cluster, calculated in the Introduction from the results of Perry et al. (1978), Delgado et al. (1992), and Peña and Peniche (1994). This value, equal to 10.0 ± 0.3 mag, leads to \( M_V = -1.9 ± 0.3 \) mag. Taking into account the bolometric correction from Table 7 of Code et al. (1976) for the \( T_{\text{eff}} \) value obtained in the preceding paragraph, one gets \( \log L/L_\odot = 3.46 ± 0.12 \).

Note that the star’s \( \beta \)-index is inconsistent with the value of \( M_V = -1.9 \) mag just derived. Indeed, the mean \( \beta \)-index computed from all available data is equal to 2.603. A look at Crawford’s (1978) Table II shows that this value is too small for a luminosity class V star having \( c_0 = 0.16 \) mag. As already noted by Delgado et al. (1992), the \( \beta \) index is apparently affected by emission. This conclusion is corroborated by our finding of emission at H\( \alpha \) (see Section 4.2).

We shall now examine the three hypotheses put forward for explaining the observed frequency of 3.7477 d\(^{-1}\). The first hypothesis is confronted with the results of linear non-adiabatic pulsation calculations in Fig. 5. This figure shows V 917 Ori in the HR diagram (solid circle with error bars). Also plotted in Fig. 5 are the Warsaw-New Jersey evolutionary tracks for the initial chemical composition of \( X = 0.70 \) and \( Z = 0.02 \) (solid lines). On the tracks, all models for which the linear nonadiabatic calculations predict a pulsation mode with the harmonic degree \( \ell \leq 2 \) and the frequency equal to 3.7477 d\(^{-1}\) are indicated. The cross indicates the model with an \( \ell = 1 \) mode; in the remaining cases, \( \ell = 2 \). The modes are pulsationally unstable in the 9 M\(_\odot\) models; the 8 M\(_\odot\) and 7 M\(_\odot\) models are stable. The evolutionary and pulsation data have been kindly communicated to us by Dr. A.A. Pamyatnykh.

As can be seen from Fig. 5, V 917 Ori has the luminosity about 3 \( \sigma \) smaller than the models with unstable modes along the 9 M\(_\odot\) evolutionary track. The models with a frequency equal to the observed one that are closer to V 917 Ori are pulsationally stable. However, these models may become unstable if the metal abundance were somewhat increased (see, e.g., Pamyatnykh 1999). Without a more detailed discussion of this point, the hypothesis of pulsation, although not entirely successful, should be retained.

The second hypothesis, i.e., that of rotational modulation, requires the observed frequency, \( f = 3.7477 \) d\(^{-1}\), to be equal to the frequency of rotation of the star, \( f_{\text{rot}} \), or to twice the frequency of rotation. Both such cases have been observed in the light variations of the \( \lambda \) Eri stars (see, e.g., Balona et al. 1991). For the ra-
adius of 4.4 R\(_{\odot}\), implied by the star’s effective temperature and luminosity derived above, the equatorial velocity of rotation would be equal to 834 km/s if \( f = f_{\text{rot}} \), or 417 km/s if \( f = 2 f_{\text{rot}} \). The first of these numbers is greater than the critical velocity of rotation of an early B star (Collins 1974), while the second is smaller. We conclude that the rotation hypothesis cannot be rejected. However, the hypothesis is somewhat flawed in at least two respects. First, 417 km/s is rather close to the critical velocity of rotation. Therefore, one would expect to see much stronger line emission than actually observed. Second, not many \( \lambda \) Eri stars have double-wave light-curves, and those which do tend to switch to the single-wave state (Cuypers et al. 1989). In case of V 917 Ori this has not been observed.

In order to examine the third hypothesis, i.e., that of an ellipsoidal light-variation in a binary system with \( f_{\text{orb}} = f/2 \), we need to know the mass of V 917 Ori. In Fig. 5, the star lies between the 7 M\(_{\odot}\) and 8 M\(_{\odot}\) evolutionary tracks. Given the radius, the hypothesis has a better chance of surviving for the higher mass. However, even for a primary having a mass of 8 M\(_{\odot}\), the radius of 4.4 R\(_{\odot}\) is a factor of about 1.5 too large to be accommodated in a Roche model with \( f_{\text{orb}} = f/2 \) (Polubek, private communication). We conclude that the third hypothesis is untenable.

![Fig. 5. NGC 2169-5=V 917 Ori in the HR diagram (solid circle with error bars). The star’s effective temperature was derived from the \( c_0 \) index and the luminosity was obtained from the distance modulus of the cluster. Also shown are the \( X = 0.70, Z = 0.02 \) Warsaw-New Jersey evolutionary tracks (solid lines). The dots, the cross, the open circle and the triangle mark the 9 M\(_{\odot}\), 8 M\(_{\odot}\), and 7 M\(_{\odot}\) models that have a pulsation mode with the frequency equal to 3.7477 d\(^{-1}\). See text for details.](image)

Without further data it is not possible to decide whether the 3.7477 d\(^{-1}\) light-variation is caused by pulsation or rotational modulation. The situation would be different if we had assumed WEBDA’s distance modulus mentioned in the Introduction. Instead of \( \log L/L_{\odot} = 3.46 \), used in the above discussion, we would then have \( \log L/L_{\odot} = 3.76 \). This value would eliminate not only the third, but also
the second hypothesis, leaving pulsation as the sole possibility. In addition, in Fig. 5 the star would fall within 1σ of the 9 M\(_\odot\) evolutionary track and the unstable 3.7477 d\(^{-1}\) pulsation modes. On the other hand, if \(\log L/L_\odot\) were smaller than 3.3, rotational modulation and binarity would both be feasible, whereas pulsation would become unlikely. Thus, determining the cause of the 3.7477 d\(^{-1}\) variation may help to pinpoint the luminosity of the star and the distance modulus of the cluster.

Let us now return briefly to the residual light-variation of V 917 Ori seen in Fig. 3 (middle). In view of the Balmer-line emission, suspected by Delgado et al. (1992) and confirmed in Section 4.2, an erratic, Be-type activity comes to mind as the most likely hypothesis.

**NGC 2169-12=V 1356 Ori.** The star was discovered to be variable in light by Delgado et al. (1992). Maitzen and Lebzelter (1993) derived a period of 1.56 d from meager photometric data. In addition, from four medium-dispersion spectra they found large variation in the intensity of the Si II 4128-31 doublet. From this, they classified the star as a CP2 Si variable.

Maitzen and Lebzelter’s (1993) period has been questioned by Renson (1994) who, using the same data, obtained a period equal to 0.606 d, close to a 1-cycle-per-sidereal-day alias of 1.56 d. Subsequently, from four nights of \(uvby\) CCD observations, Manfroid and Renson (1994) proposed four possible values of the period: 3.111 d, 1.557 d, 1.254 d, and 0.618 d, indicating 1.557 d as the most probable one. However, they warned that their results “do not unambiguously solve the problem of the period of NGC 2169-12.”

Fortunately, ours do. This can be seen from the LS power spectrum displayed in the left panel of Fig. 6: the peak at 0.639 d\(^{-1}\) (period equal to 1.565 d) is much higher than its 1-cycle-per-sidereal-day aliases at 0.363 d\(^{-1}\) and 1.642 d\(^{-1}\). Note that our period of 1.565 d differs from that of Maitzen and Lebzelter (1993) and the second period of Renson (1994) by about 2/3 and 4/3 cycles per year, respectively. Since these authors used data obtained three years apart, the differences are understandable. In any case, Maitzen and Lebzelter’s (1993) original period is close to the correct period we derived.

In the power spectrum obtained after prewhitening the data with the period of 1.565 d there are no peaks higher than 0.12; the highest one has the frequency equal to 1.278 d\(^{-1}\), the harmonic of 0.639 d\(^{-1}\).

**NGC 2169-14=V 1154 Ori.** From five \(BV\) observations, obtained on one night, Sagar (1976) found the star to be variable and derived a period of 0.22 d. Using the star’s membership in the cluster as a premise, he then went on to classify NGC 2169-14 as an RRc variable! Surprisingly, this sadly incorrect classification is repeated in the GCVS.

We have used NGC 2169-14 as a comparison star for V 917 Ori and found it constant in light (see the bottom panels of Figs. 3 and 4).

**NGC 2169-25.** The variability of this star was discovered in the present work
Fig. 6. Left: the LS power spectrum of the differential $V$ magnitudes “V 1356 Ori minus NGC 2169-13”; the frequency of the highest peak is equal to 0.639 d$^{-1}$ (period equal to 1.565 d). Right: the differential magnitudes plotted as a function of phase of this period; the epoch of phase zero is HJD 2452270.000.

from 3265 differential $V$ magnitudes “NGC 2169-25 minus 15.” The range is equal to about 0.1 mag. No period could be found. There are not enough data to decide whether NGC 2169-25 is a pre-main-sequence cluster member or a heavily reddened background star.

**NGC 2169-32.** This is the second star we discovered in this work to be variable in light. The 3265 differential $V$ magnitudes “NGC 2169-32 minus 13” show a range equal to about 0.2 mag. In the LS power spectrum there is a peak at 1.2523 d$^{-1}$, but a sine-curve of this frequency reduces the variance of the data by only 40% and the phase diagram does not look convincing. Moreover, prewhitening does not remove low frequency power. We conclude that the variation of NGC 2169-32 is irregular, with time scales of the order of days.

The individual $V$-filter observations of all stars discussed in this Section are available in electronic form from the Acta Astronomica Archive.

### 4. The Color-Magnitude Diagram and H$\alpha$ Photometry

#### 4.1. Transformation to the Standard System

As far as we are aware, there are no standard $I_C$ magnitudes for NGC 2169, while standard $V$ magnitudes are available. Therefore, only our $V$-filter data could be transformed to the standard system.

The procedure was as follows. First, we computed average differential magnitudes with respect to the mean brightness of two comparison stars, NGC 2169-15 and NGC 2169-18. Then, twelve stars with known $V$-magnitudes were selected as standard stars. Except for NGC 2169-8, all these stars are the brightest probable members of the cluster with instrumental $(v-i)$ colors in the narrow range from $-0.2$ mag to $0.0$ mag. For NGC 2169-8 the $(v-i)$ index is equal to 0.9 mag. Using these stars we derived the following transformation equation:

$$V - v = 0.036(v - i) + 11.428 \quad \sigma = 0.010$$
Fig. 7. The color-magnitude diagram for NGC 2169. The abscissa is the instrumental \((v-i)\) color-index, and the ordinate is the \(V\) magnitude, computed from the transformation equation given in the text. The variable stars are shown with asterisks, while the remaining stars, with filled circles. Encircled symbols indicate the two stars for which we detected emission at \(H\alpha\).

where the uppercase letters denote standard magnitudes, while the lowercase letters, the instrumental magnitudes; \(\sigma\) is the standard deviation of the fit. Note that although the color term in the above equation could not be derived without NGC 2169-8, the only red standard star available, there is no reason to question its reliability because neither WEBDA nor our data show any evidence that the star is variable in light.

The standard \(V\) magnitudes are available from the authors upon request.

The \(V\) vs. \((v-i)\) color-magnitude diagram for NGC 2169 is presented in Fig. 7. The variable stars are plotted as asterisks; the two stars showing \(H\alpha\) emission (see below) are indicated with open circles. These stars (and two stars, V 916 and V 1154 Ori, found constant in light in Section 3) are labeled with their GCVS des-
ignations or numbers from Fig. 1.

As can be seen from Fig. 7, NGC 2169-8 is clearly not a member. The remaining stars with $V < 13$ mag form the cluster’s main sequence. The scattered points below $V = 13$ mag may represent a mixture of pre-main-sequence members of the cluster and background stars.

4.2. The Hα Photometry

In an attempt to detect Be stars in NGC 2169, we took the Hα observations mentioned in Section 2. From these data we derived the $\alpha$ index, defined as the mean difference between the narrow- and wide-filter magnitudes (see Paper II for details).

Because of the small width of the narrow filter, the $\alpha$ index could be derived with sufficient accuracy only for the 14 brightest stars. These data are plotted as a function of the $V$ magnitude in Fig. 8. As can be seen from Fig. 8, two stars, NGC 2169-5=V 917 Ori and NGC 2169-8 show mild emission at Hα.

![Fig. 8. The $\alpha$ index for the brightest stars in the observed field of NGC 2169, displayed as a function of the $V$ magnitude. Stars showing Hα emission are plotted as open circles. The dashed line indicates the expected value of the $\alpha$ index for zero equivalent-width of the Hα line.](image)

5. Conclusions

Our results can be summarized as follows: (1) Of the two NGC 2169 stars classified in the GCVS as β Cep variables, V 916 Ori is constant in light, while V 917 Ori has a different period than that listed in the GCVS. (2) The light-variation of V 917 Ori consists of a periodic term, having a period equal to 0.267 d (frequency 3.7477 d$^{-1}$), and an erratic component, probably caused by a Be-type activity. (3) The cause of the periodic term in the variation of V 917 Ori cannot be unambiguously determined from the data at hand. (4) The period of V 1356 Ori is equal to 1.565 d. (5) V 1154 Ori is not an RRc variable; in fact, it is constant in light. (6) NGC 2169-25 and NGC 2169-32 are variable in light with the $V$ range
amounting to 0.1 mag and 0.2 mag, respectively. (7) V917 Ori and NGC 2169-8 show mild emission at Hα. (8) In the color-magnitude diagram of NGC 2169 there is a population of faint stars which may represent a mixture of pre-main-sequence members of the cluster and background stars.

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