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Research Note

Three periodic variables of early B spectral type*

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Abstract. Using all available *uvby* observations we find that HR 5375, σ Lupi, and HR 6174 are small-amplitude, singly-periodic variables, having periods equal to 1.5439, 3.0186 ±0.0004 and 1.59416±0.00013 d, respectively. We point out that while the stars may be ellipsoidal variables, the existing data are insufficient to rule out two other hypotheses, namely, those of rotational modulation and high overtone *g*-mode pulsations.

Key words: photometry – stars: individual – stars: variable – stars: early-type

1. Introduction

HR 5375 (B1 III, $V=6.09$) was found to be variable by Sterken & Jerzykiewicz (1983; henceforth SJ83). The light variation of σ Lupi (=HR 5425, B2 III, $V=4.42$) was noted by vander Linden & Sterken (1987; henceforth vLS87). HR 6174 (B2.5 IV, $V=5.83$) was suspected to be variable by SJ83; its variability was confirmed by vLS87. In February 1985 the stars were put on the long-term photometry of variables (LTPV) program at the European Southern Observatory (Sterken & Manfroid 1988; Manfroid et al. 1991). Until September 1986, about one-hundred *uvby* observations of each star were obtained. In the present note we give an account of our analysis of these and the earlier data.

2. HR 5375

In the LTPV program, this star was B7015, that is, the second comparison star for P7015=σ Lupi, which is discussed in the next section. Fortunately, the first comparison star, A7015= HD 130572 (A0 V, $V=6.56$), has been found constant to within 4 mmag by vLS87. Using all LTPV observations, we could form 103 differential *uvby* magnitudes "HR 5375 *minus* HD 130572". These data, spaced at irregular intervals not shorter than about one day, span 575 d, from JD 2446100 to JD 2446675. Since the observations were obtained in three different instrumental systems, we reduced the differential magnitudes to a common zero level by subtracting mean values, derived separately for each system. Details of the observational procedure, instrumental systems, reductions, and the time distribution of the observations can be found in Manfroid et al. (1991).

In order to examine the data for the presence of periodicities, we used Lomb's (1976) method of least-squares (LS) frequency analysis. In this method, the power spectrum is obtained by fitting sine curves to the data by least-squares and plotting the normalized reduction in the sum of squares of residuals, $p(f)$, as a function of frequency.

The LS power spectrum of the differential *b* magnitudes "HR 5375 *minus* HD 130572" is shown in Fig. 1. The *u*, *v*, and *y* power spectra are not shown, because all four spectra are almost identical. In particular, the highest peak occurs at 0.6477 d^{-1} in all spectra. The corresponding period is equal to 1.5439 d. The data, phased with this period, are plotted in Fig. 2 as open circles. The solid lines in this figure are sine curves of the same period, fitted to the data by the method of least squares. The parameters of the fits are given in Table 1.

The period of 1.5439 d fits also the SJ83 observations of HR 5375, as can be seen from Fig. 3. These ten observations were obtained on four nights in June 1977. Two comparison stars, HR 5401 (Am, $V\doteq5.83$) and HR 5412 (B8 Vn, $V=5.50$), were used. The points plotted in Fig. 3 are differential *uvby* magnitudes "HR 5375 *minus* the mean of the comparison stars". Their distribution in phase is so favourable that they could be fitted with the 1.5439 d sine-curves by the method of least squares. The sine curves are shown as solid lines in the figure. As can be seen from Table 2, which contains the parameters of the fits, the 1977 amplitudes are not significantly different from the 1985–1986 ones, given in Table 1. The largest difference, equal to 2.8 mmag, occurs in *u*, but it has a standard deviation of 2.5 mmag. Unfortunately, because of the large gap between the SJ83 and LTPV data, the question whether the coherence of the 1.5439 d variation of HR 5375 has been maintained from 1977 to 1985–1986 cannot be answered.

The LS power spectra of the LTPV data prewhitened with the 1.5439 d variation show only noise. Thus, the scatter seen in Fig. 2, and the large standard deviations in Table 1, indicate the presence of incoherent variations. The very small scatter of the differential magnitudes "σ Lupi *minus* HD 130572" (see the next section) proves that the incoherent variations, whether intrinsic or observational, are connected with HR 5375.

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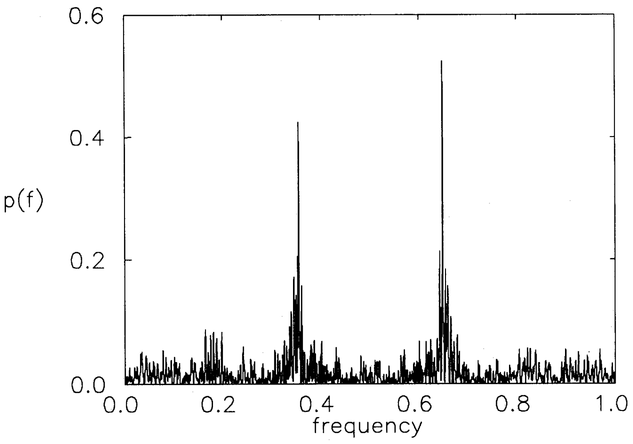

Fig. 1. The LS power spectrum of the LTPV *b* observations of HR 5375

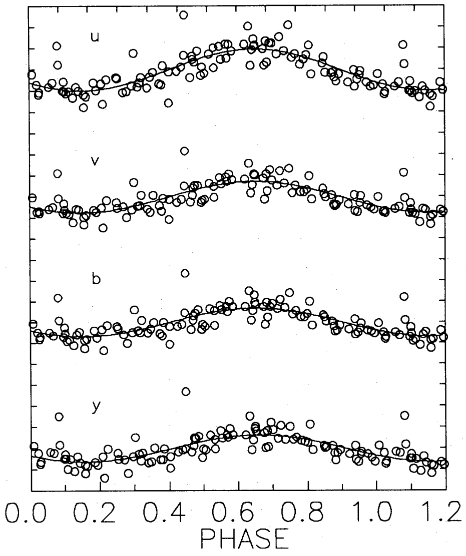

Fig. 2. The LTPV observations of HR 5375 phased with the period of 1.5439 d. The epoch of phase zero is HJD 2446099. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 20 mmag. The solid lines are sine curves computed using the parameters listed in Table 1

Table 1. Parameters of a least-squares sine fit to the LTPV observations of HR 5375, derived using the period of 1.5439 d. The standard deviations, SD, the mean differential magnitudes, ⟨Δ*m*⟩, and the amplitudes, *A*, are expressed in mmag

Filter	SD	⟨Δ*m*⟩	*A*	HJD of maximum light
u	11.2	0.5±1.1	19.5±1.6	2446100.003±0.020
v	9.4	0.4±0.9	14.7±1.3	.002±0.022
b	9.4	0.3±0.9	13.6±1.3	.008±0.024
y	9.9	0.3±1.0	12.6±1.4	.019±0.027

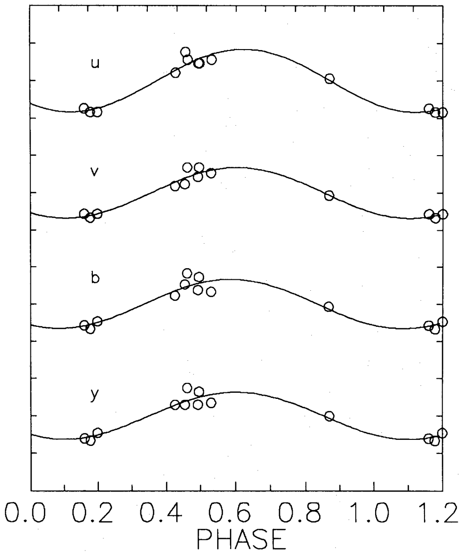

Fig. 3. The SJ83 observations of HR 5375 phased with the period of 1.5439 d. The epoch of phase zero is HJD 2443315. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 20 mmag. The solid lines are sine curves computed using the parameters listed in Table 2

Table 2. Parameters of a least-squares sine fit to the SJ83 observations of HR 5375, derived using the period of 1.5439 d

Filter	SD	⟨Δ*m*⟩	*A*	HJD of maximum light
u	3.4	−914.8±1.5	16.7±1.9	2443315.960±0.029
v	3.0	122.6±1.3	13.6±1.6	.935±0.031
b	4.3	352.5±1.8	13.3±2.2	.906±0.048
y	3.8	443.8±1.6	12.5±2.0	.929±0.044

3. σ Lupi

From the LTPV observations we computed the differential *uvby* magnitudes "σ Lupi *minus* HD 130572" and reduced them to a common zero level. The number of the differential magnitudes and their distribution in time was, of course, the same as in the case of HR 5375, discussed in the preceding section. The LS power spectrum of the *b* data is shown in Fig. 4. The highest peak in the frequency spectrum occurs at 0.3311 d^{-1}, corresponding to the period of 3.020 d. The phase diagrams, plotted using this period, are shown in Fig. 5. Table 3 contains parameters of the sine curves seen in this figure.

Figure 6 shows the observations of vLS87 phased with the same period. These data consist of 22 differential *uvby* magnitudes "σ Lupi *minus* HD 130572", obtained in the interval from May 1982 to June 1984. Parameters of the sine curves (solid lines), fitted to the data by least-squares, are given in Table 4. The amplitudes in this table agree very well with those in Table 3. Moreover, assuming that 329 cycles elapsed between the epochs of maximum light in the two tables, we get an improved value of the period equal to 3.0186±0.0004 d.

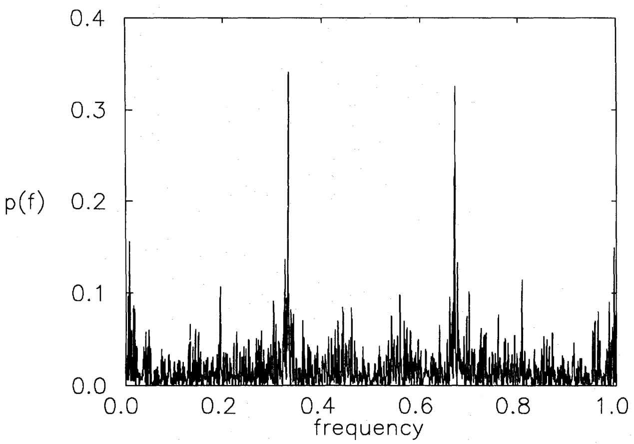

Fig. 4. The LS power spectrum of the LTPV b observations of σ Lupi

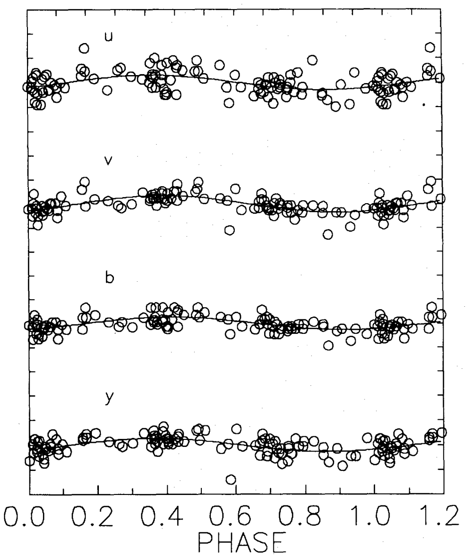

Fig. 5. The LTPV observations of σ Lupi phased with the period of 3.020 d. The epoch of phase zero is HJD 2446099. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 10 mmag. The solid lines are sine curves computed using the parameters listed in Table 3

Table 3. Parameters of a least-squares sine fit to the LTPV observations of σ Lupi, derived using the period of 3.020 d

Filter	SD	$\langle \Delta m \rangle$	A	HJD of maximum light
u	4.3	0.1 ± 0.4	3.0 ± 0.6	2446100.08 ± 0.10
v	3.1	0.0 ± 0.3	3.5 ± 0.4	$.18 \pm 0.06$
b	2.7	0.2 ± 0.3	2.7 ± 0.4	$.24 \pm 0.07$
y	3.2	0.0 ± 0.3	2.7 ± 0.4	$.11 \pm 0.08$

The alias peak in the LS frequency spectrum in Fig. 4 corresponds to a period of 1.489 d. This period represents the LTPV and vLS87 data almost as well as the 3.020 d one does. In this case, an improved value of the period would be equal to 1.48926 ± 0.00009 d.

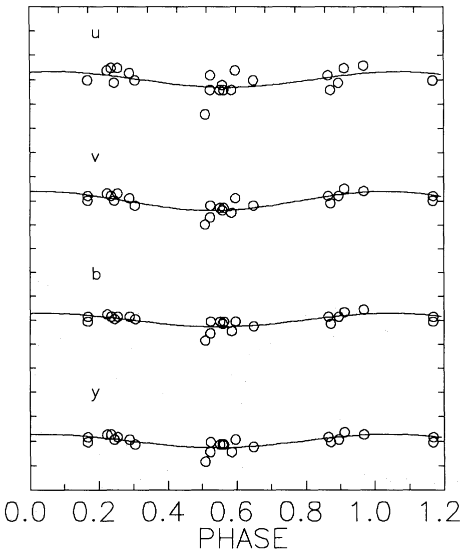

Fig. 6. The vLS87 observations of σ Lupi phased with the period of 3.020 d. The epoch of phase zero is HJD 2445107. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 10 mmag. The solid lines are sine curves computed using the parameters listed in Table 4

Table 4. Parameters of a least-squares sine fit to the vLS87 observations of σ Lupi, derived using the periof of 3.020 d

Filter	SD	$\langle \Delta m \rangle$	A	HJD of maximum light
u	4.1	-3597.3 ± 0.9	3.2 ± 1.3	2445107.21 ± 0.19
v	2.4	-2397.9 ± 0.5	4.0 ± 0.7	$.09 \pm 0.09$
b	2.2	-2215.6 ± 0.5	2.9 ± 0.7	$.14 \pm 0.11$
y	2.0	-2121.4 ± 0.5	2.7 ± 0.6	$.12 \pm 0.11$

4. HR 6174

In the LTPV program, this star is P7016. The comparison stars are A7016=HR 6209 (B6–7V, $V=6.12$) and B7016=HR 6214 (B3 V, $V=5.71$). Using all LTPV observations, we could form 95 differential *uvby* magnitudes "HR 6174 *minus* the mean of HR 6209 and HR 6214". These data span an interval of 523 d, from JD 2446153 to JD 2446675. The LS power spectrum of the differential b magnitudes is shown in Fig. 7. The highest peak in the figure corresponds to the period of 1.594 d. The phase diagrams, plotted using this period, are shown in Fig. 8, and parameters of the sine curves seen in this figure are listed in Table 5.

The LS power spectra, computed after prewhitening the data with these sine curves, show no peaks above noise. We conclude that HR 6174 is singly periodic.

As mentioned in the Introduction, vLS87 also observed the star. Their results consist of 21 differential *uvby* magnitudes "HR 6174 *minus* HR 6209", obtained between May 1982 and June 1984. In Fig. 9 these observations are phased with the period mentioned above. Parameters of the sine curves shown in this figure are given in Table 6. From the numbers in Tables 5 and 6 it follows that (1) the amplitudes of the 1.594 d variation of HR 6174

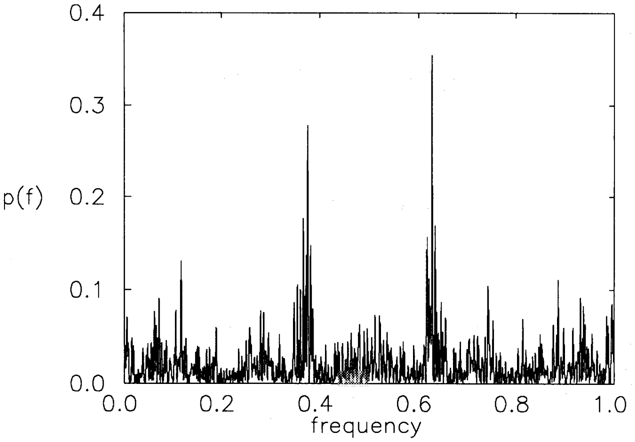

Fig. 7. The LS power spectrum of the LTPV *b* observations of HR 6174

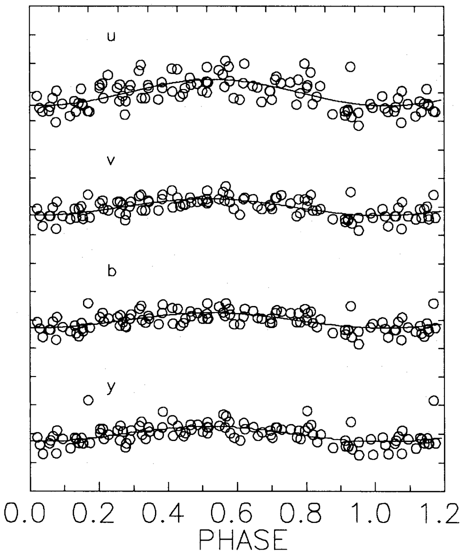

Fig. 8. The LTPV observations of HR 6174 phased with the period of 1.594 d. The epoch of phase zero is HJD 2446152. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 20 mmag. The solid lines are sine curves computed using the parameters listed in Table 5

Table 5. Parameters of a least-squares sine fit to the LTPV observations of HR 6174, derived using the period of 1.594 d

Filter	SD	$\langle \Delta m \rangle$	A	HJD of maximum light
u	8.3	0.2 ± 0.9	9.0 ± 1.2	2446152.850 ± 0.034
v	5.1	0.2 ± 0.5	5.8 ± 0.8	$.823 \pm 0.032$
b	5.1	0.1 ± 0.5	5.3 ± 0.8	$.836 \pm 0.035$
y	5.8	0.2 ± 0.6	5.3 ± 0.8	$.826 \pm 0.040$

did not change significantly during the four-year interval of observations, from 1982 to 1986, and (2) an improved value of the period is 1.59416 ± 0.00013 d.

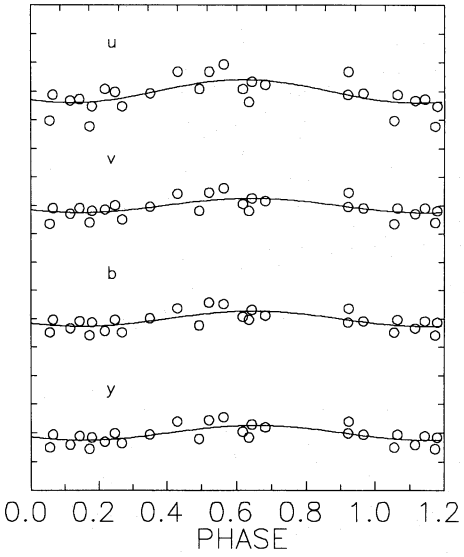

Fig. 9. The vLS87 observations of HR 6174 phased with the period of 1.594 d. The epoch of phase zero is HJD 2445114. Mean light levels are arbitrary. Tick marks along the vertical axis are spaced at intervals of 20 mmag. The solid lines are sine curves computed using the parameters listed in Table 6

Table 6. Parameters of a least-squares sine fit to the vLS87 observations of HR 6174, derived using the period of 1.594 d

Filter	SD	$\langle \Delta m \rangle$	A	HJD of maximum light
u	9.1	-385.5 ± 2.0	8.0 ± 3.0	2445114.99 ± 0.10
v	5.7	-244.9 ± 1.3	5.0 ± 1.9	5.03 ± 0.09
b	5.2	-264.7 ± 1.2	5.4 ± 1.7	$.03 \pm 0.08$
y	5.1	-296.2 ± 1.1	5.1 ± 1.7	$.05 \pm 0.08$

5. Discussion

Small-amplitude variables of early to mid-B spectral type, having periods in the range from about one to three days, are frequent by-products of photometric searches for β Cephei stars. Until recently such objects were dismissed as ellipsoidal variables and seldom investigated in any detail. However, similar periods were found in a number of Be and Bn stars by Balona and his co-workers (Balona et al. 1987; van Vuuren et al. 1988; Cuypers et al. 1989; Balona et al. 1991). These stars, named "λ Eri variables" by Balona (1990, 1991), were explained by him in terms of rotational modulation caused by active photospheric areas (that is, spots) and matter trapped above the photosphere by a magnetic field. As shown by Balona (1991) and Balona et al. (1991), matter above the photosphere in corotation with the star must be included in the model because spots alone, while sufficient for explaining the light variations, cannot account for the observed radial velocity variations.

The light and line-profile vriations of Be stars with periods in the above-mentioned range from about one to about three days can also be modeled using nonradial pulsation modes of low degree. This approach has been reviewed by Baade (1987).

The same range of periods is also occupied by the "mid-B variables" of Waelkens & Rufener (1985). The seven stars of this kind known so far have spectral types for B3 to B8 and the MK luminosity classes V, IV, or III. They show small-amplitude light and ultraviolet-blue colour index variations. Waelkens & Rufener (1985) suggest that nonradial pulsations in high-overtone g modes are responsible for the observed variations.

The three stars found periodic in the present investigation may all be ellipsoidal variables with orbital periods equal to twice the values derived above. Unfortunately, existing radial velocity data are insufficient to verify this prediction. Existing data are also insufficient to rule out the other two possibilities. Projected rotational velocity is known only for σ Lupi. According to the Bright Star Catalogue (Hoffleit & Jaschek 1982), $v \sin i$ for σ Lupi is equal to $84 \mathrm{~km} \mathrm{~s}^{-1}$. For a B2 III star with a radius of $8.8 R_{\odot}$ (Underhill 1982, Table 2–12) and having the rotation period equal to 3 d, $v \sin i = 84 \mathrm{~km} \mathrm{~s}^{-1}$ implies $v = 150 \mathrm{~km} \mathrm{~s}^{-1}$ and $i = 35°$. These values show that at least in the case of σ Lupi rotational modulation is a reasonable working hypothesis. Finally, nothing can be said at present about the hypothesis of g-mode pulsations, except that it may be difficult to disprove if the stars will be found to have small radial velocity ranges.

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