Astron. Astrophys. 354, 589–594 (2000)

ASTRONOMY AND ASTROPHYSICS

Period and amplitude changes in the δ Scuti star V 1162 Orionis*

T. Arentoft and C. Sterken

University of Brussels (VUB), Pleinlaan 2, 1050 Brussels, Belgium (tarentof@vub.ac.be; csterken@vub.ac.be)

Received 14 September 1999 / Accepted 23 November 1999

Abstract. We present yb time–series CCD photometry of the high–amplitude δ Scuti star V 1162 Ori. A period break and a significant decrease in amplitude (50 percent) has been reported for this star by Hintz et al. (1998). New observations carried out over two observing seasons suggest that the period found by Hintz et al. (1998) was no longer valid in early 1998, and that the period again changed during March or April 1998. The latter period change was accompanied by an increase in amplitude of the order of 10 percent.

The existing data can be explained by a frequently changing period or by a possible cyclic variation in the $O-C$ diagram indicating sudden changes, a binary system or the presence of two very closely–spaced pulsation frequencies.

Key words: methods: data analysis – techniques: photometric – stars: variables: δ Sct – stars: individual: V 1162 Ori

1. Introduction

High–amplitude δ Scuti stars are short–period pulsators, oscillating in one or two radial modes with amplitudes of a few tenths of a magnitude, with possible non–radial low–amplitude variations superimposed. They are found in the classical Cepheid instability strip on or just above the Main Sequence, in the same region as the low–amplitude multiperiodic δ Scuti stars. There are, however, certain characteristics that separate them from the low–amplitude pulsators: the amplitude of the light variations, and the fact that they are found in a very narrow strip in the HR–diagram (only 200–300 K wide), inside the δ Scuti instability strip (McNamara 1997).

The δ Scuti stars are very important objects for asteroseismic investigations, and the high–amplitude δ Scuti stars can furthermore be used as distance indicators (McNamara 1997; Petersen & Høg 1998).

Several δ Scuti stars have changing pulsation periods. Such changes are expected from stellar evolution, but many stars show period changes which currently cannot be described by stellar evolution theories, see Breger & Pamyatnykh (1998). These authors have collected data on period changes from a number of δ Scuti stars, and find that the observed change–rates are larger than what is expected from theory. The changes are furthermore equally distributed between increasing and decreasing periods, while mainly increasing periods are expected.

V 1162 Ori is a high–amplitude δ Scuti star discovered by Lampens (1985). It was later observed by Poretti et al. (1990), who found the star to be monoperiodic. They determined a period of 0.07868614 days and a V–amplitude of $0\overset{m}{.}22$. Hintz et al. (1998) observed the star several years later, and found a much smaller amplitude ($0\overset{m}{.}10$), and a different period: 0.07869165 days, implying an increase of 0.5 seconds over 8.5 years. They also saw evidence of a possible second period, but were not able to determine it from their dataset. In this paper we present the results of new CCD time–series photometry of V 1162 Ori. We address the question of period– and amplitude changes in this star, and we search for a possible second period. We present new times of maximum and minimum light, and compare with previously obtained results. We show that the light of V 1162 Ori undergoes period- and amplitude changes on a short time scale.

2. Observations and photometric reductions

The observations were carried out using the Dutch 91 cm telescope at ESO, La Silla, Chile, equipped with a 512×512 pixels CCD detector (ESO #33). The field of view was $3'5 \times 3'5$. The observations were done in the framework of *Long-Term Photometry of variables* (LTPV, Sterken 1983), during 26 nights distributed over 4 observing runs in the beginning of 1998, and during 28 nights over 3 runs in the beginning of 1999, see Table 1. The star was typically observed each night for 1–3 hours, in the Strömgren b and y filters. A total of 111 hours of time–series photometry was collected in both filters.

During the observations, image drift was kept at a very low level to minimize flat-field errors. The seeing was typically 1.5–2.5 arcseconds, and exposure times were 30–120 seconds in y and 45–140 seconds in b, depending on atmospheric conditions. The CCD detector was tested for linearity, and was found to give a linear response within a few per mille, except at very high count rates. Non–linearity was avoided by keeping the count levels well below the saturation limit.

Send offprint requests to: T. Arentoft

* Based on observations obtained at the European Southern Observatory at La Silla, Chile (applications ESO 62H–0110, 64H–0065 and 64L–0182)

Table 1. Log of CCD observations of V 1162 Ori with the Dutch 91 cm telescope at ESO, La Silla.

Run	No. of nights	No. of frames	Length (hr)
1998 January	15	1276	30.5
1998 February	5	340	9.0
1998 March	3	212	5.8
1998 April	3	106	4.4
1999 January(a)	6	502	14.8
1999 January(b)	13	970	30.0
1999 March	9	572	16.7
Total	54	3978	111.2

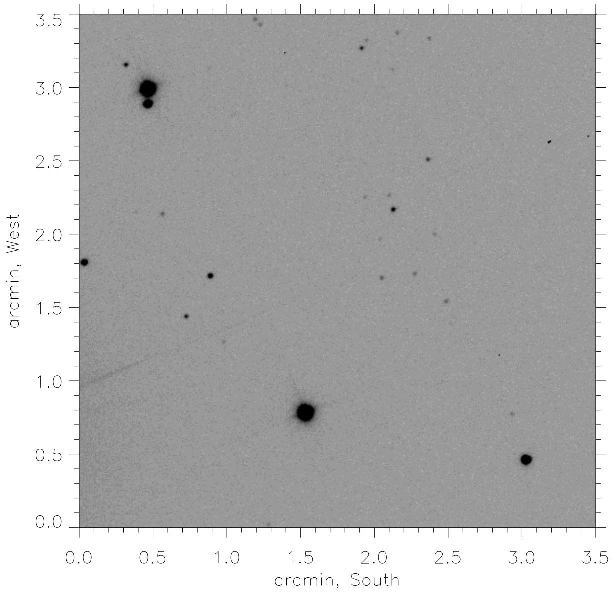

Fig. 1. CCD image of the field in Orion. The brightest star in the upper left corner (NW) is V 1162 Ori, the bright star SW of the center is the comparison star.

The observed region can be seen in Fig. 1. The field covers V 1162 Ori with a $3\overset{m}{.}1$ fainter close neighbour in the NW corner, and two constant stars, one of the same brightness as V 1162 Ori and the other $2\overset{m}{.}8$ fainter. The brightest of the constant stars (GSC 4778-00019) is used as comparison star to V 1162 Ori, the fainter one is used to check the constancy of the comparison star. The comparison star is star 2 in the CCD reductions of Hintz et al. (1998). The properties of V 1162 Ori and the comparison star are listed in Table 2.

The CCD–frames were BIAS–corrected, and flat–fielded using skyflats obtained at the beginning and end of each night. The photometric reduction was done using the software package MOMF (Kjeldsen & Frandsen 1992). This package is designed for CCD time–series photometry and makes use of a combined PSF/Ap photometry with a local sky determination. The contribution of the star close to V 1162 Ori is subtracted from the frame before the magnitude of V 1162 Ori is determined. The resulting data tables will be made available in due time.

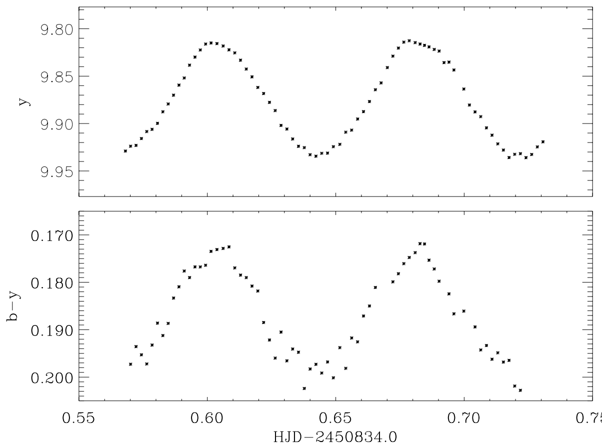

Fig. 2. Examples of light curves, from the night 1998 Jan 20 for V 1162 Ori.

3. Analysis

3.1. Light curves

The light curves from each observing night typically cover one minimum and one maximum, with a few longer stretches in between. An example can be seen in Fig. 2: the quality is generally good, see the top panel. The difference between the two constant stars shows no sign of variability, and the rms–scatter is typically about 4 mmag. Since one of these stars is about 3 magnitudes fainter than V 1162 Ori and the comparison star, we expect the rms-scatter in the light curve of V 1162 Ori to be lower than 4 mmag (see Sect. 3.4 for a discussion of the formal noise level).

From the light curves it became clear that the amplitude of the light variations in V 1162 Ori increased significantly towards April 1998. From January to March 1998 the amplitude (full light range) in y, which can be compared with the V–amplitude of $0\overset{m}{.}10$ found by Hintz et al. (1998), was $0\overset{m}{.}11$–$0\overset{m}{.}12$ (as derived from the individual light curves). The quoted range in amplitude reflects cycle–to–cycle variations as well as uncertainties in the determination of the amplitudes, which are formally derived in Sect. 3.4. In April 1998 the amplitude in y had grown to $0\overset{m}{.}14$. Cycle–to–cycle amplitude variations of this order were also found by Poretti et al. (1990), but in 1998 there appears to have occurred an overall increase in amplitude. In b the amplitude increased from $0\overset{m}{.}14$–$0\overset{m}{.}15$ in January–March 1998 to $0\overset{m}{.}17$ in April 1998. In early 1999 the amplitude was a little lower than in April 1998, $0\overset{m}{.}12$–$0\overset{m}{.}13$ in y, and $0\overset{m}{.}15$–$0\overset{m}{.}16$ in b. However, in March 1999 the amplitude had again increased, to $0\overset{m}{.}15$–$0\overset{m}{.}16$ in y and $0\overset{m}{.}19$–$0\overset{m}{.}20$ in b. During one night in January 1999 we have observed through the V–filter, and found an amplitude of $0\overset{m}{.}125$, thus similar to the y–amplitude, as one would expect.

In the lower panel of Fig. 2 we show an example of a colour curve. Since b and y frames were obtained sequentially, we constructed the $b - y$ index from an observed y magnitude and the corresponding interpolated b magnitude.

In both the upper and lower panel of Fig. 2 we have matched the zero–points to the indices determined by Hintz et al. (1998).

Table 2. Properties of V 1162 Ori and its comparison star. Coordinates, V–magnitude and $B-V$ are taken from the SIMBAD database, $v \sin i$ is taken from Solano & Fernley (1997), the remaining parameters are taken from Hintz et al. (1998).

Star	α_{2000}	δ_{2000}	V	$B-V$	$b-y$	E(b-y)	β	$v \sin i$ (km/s)	$T_{\rm eff}$ (K)	$M_{\rm V}$	M $M_{\odot}$	Age Gyr
V1162 Ori	05 32 01.9	-07 15 05	9.89	0.38	0.187	0.021	2.768	46.0	7540	2.1	1.8	0.60
GSC 4778-00019	05 32 06.9	-07 17 52	10.0	1.40								

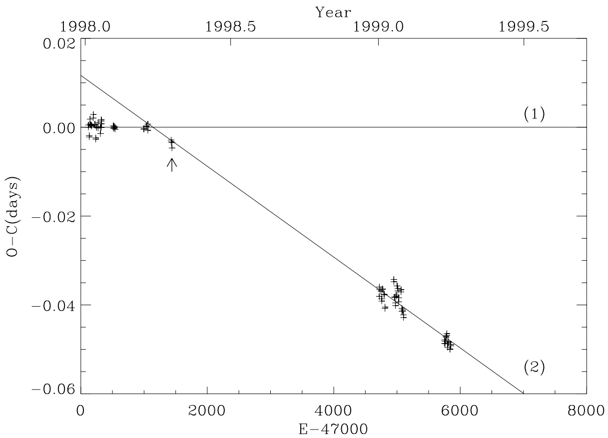

Fig. 3. $O-C$ diagram for V 1162 Ori, based on the times of maximum light in both the y and b filter. The leftmost data-points corresponds to observations made in January 1998, the rightmost to observations from March 1999. The points from April 1998 are marked by an arrow. (1) and (2) refer to Eqs. (1) and (2) in the text.

On the basis of observations of 4–5 standard stars (Jønch–Sørensen 1994) each night during a few photometric nights, we obtained zero–point shifts that yield, within the observational errors, the same y, $b-y$ indices as found by Hintz et al. (1998).

3.2. $O-C$ diagrams

We have used the observed times of minimum and maximum light to investigate the pulsational period of V 1162 Ori. The times of extreme light were determined by fitting a third degree polynome to the light curves in the vicinity of each extremum. The times of minimum and maximum light can be seen in Table 3. We have used the count scheme from Table 1 of Hintz et al. (1998). It should be noted that the zero–point of this scheme is not well defined due to the period break in between the observations of Poretti et al. (1990) and Hintz et al. (1998). The first $T_{\rm max}$ of Hintz et al. (1998), given in their Table 1 ($HJD_{\rm max} = 49992.8337, E = 36627$) is consistent with the E–numbers of our times of maximum light, but the E–numbers for the times of maximum from Poretti et al. (1990), given in the same table, may be off by one or two cycles.

After the observations in the beginning of 1998, it was clear that the period determined by Hintz et al. (1998) did not fit our data. The ephemeris given by Eq. 2 in that paper agreed fairly well with our times of maximum light in the beginning of January 1998, but the $O-C$ value grew towards March and April that year, see Arentoft & Sterken (1999). We searched for the period in the 1998–data, and found that a linear fit could be obtained from the January–March 1998 times of maximum, yielding a period of 0.0786987 days:

$$HJD_{max} = 2450818.6262 + 0\overset{d}{.}0786987 \times E \qquad (1)$$
$$\pm 0.0004 \pm 0.0000007$$

This fit is represented by the horizontal line in Fig. 3. However, the times of maximum found in April 1998 are not reproduced with the above period, as can also be seen in Fig. 3. The data–points from this run, which are marked by the arrow, lie significantly below the horizontal line. Furthermore, the increased amplitude, discussed in Sect. 3.1, indicates that changes have occurred. Including the data obtained in 1999, it was clear that the period had changed. Instead, a shorter period could be found using a linear fit to the April 1998 and the 1999 times of maximum, demonstrated by the inclined fit in Fig. 3:

$$HJD_{max} = 2450921.4826 + 0\overset{d}{.}07868892 \times E \qquad (2)$$
$$\pm 0.0001 \pm 0.00000003$$

This finding suggests that V 1162 Ori has undergone two period changes within only a few months, one in late 1997 or early 1998, and one in March/April 1998.

A different approach is to fit the times of maximum light from Hintz et al. (1998) together with our new data. The data from Poretti et al. (1990) are not included because of the period break reported by Hintz et al. (1998). Such a fit gives a value for the period of 0.07869122 days, which is close to the value found by Hintz et al. (1998), and the corresponding $O-C$ diagram is shown in Fig. 4. This figure suggests that the times of maximum light can be described with only one value of the period, with a quasi–cyclic $O-C$ variation superimposed. The ephemeris found from this dataset is:

$$HJD_{max} = 2449992.8403 + 0\overset{d}{.}078691216 \times E \qquad (3)$$
$$\pm 0.0001 \pm 0.000000005$$

The cyclic behavior could be due to a beat between two very closely–spaced frequencies (see Sect. 3.4), or to the presence of a binary companion. In the latter case, the cyclic variations can be caused by light–time effects due to orbital motion, as was seen in some other δ Scuti stars, e.g. CY Aqr (Ai-Ying & Jian-Ning 1998) and AD CMi (Jian-Ning & Shi-Yang 1996). The evidence presented in Fig. 4 is not convincing, but a cyclic variation can also not be completely ruled out.

By fitting a sine-function to the $O-C$ values in Fig. 4 we obtain a period of the cyclic variation of about 2 years, and an amplitude of 0.0075 days. Using the well-known formulae for

Table 3. New times of maximum and minimum light (average of y and b filters, HJD-2,400,000.0). The cycle count scheme is based on Hintz et al. (1998).

E	T_{max} y,b	E	T_{max} y,b	E	T_{min} y,b	E	T_{min} y,b
47121	50818.6261	51759	51183.5936	47121	50818.6661	51759	51183.6387
47133	50819.5681	51772	51184.6191	47133	50819.6084	51771	51184.5841
47146	50820.5945	51797	51186.5854	47145	50820.5573	51809	51187.5705
47159	50821.6169	51810	51187.6055	47158	50821.5817	51950	51198.6682
47172	50822.6398	51950	51198.6295	47171	50822.6030	51962	51199.6144
47184	50823.5809	51963	51199.6488	47197	50824.6474	51975	51200.6366
47197	50824.6094	51975	51200.5916	47210	50825.6735	52000	51202.6062
47223	50826.6537	51988	51201.6166	47222	50826.6188	52013	51203.6276
47236	50827.6736	52001	51202.6419	47248	50828.6611	52025	51204.5691
47249	50828.6993	52013	51203.5854	47273	50830.6306	52026	51204.6462
47273	50830.5885	52026	51204.6062	47298	50832.5964	52051	51206.6174
47311	50833.5779	52064	51207.5988	47324	50834.6428	52063	51207.5595
47324	50834.6033	52077	51208.6177	47325	50834.7218	52064	51207.6392
47325	50834.6808	52089	51209.5618	47527	50850.6200	52076	51208.5816
47515	50849.6333	52103	51210.6624	47540	50851.6430	52089	51209.6070
47527	50850.5776	52750	51261.5750	47552	50852.5887	52102	51210.6281
47541	50851.6793	52762	51262.5192	47578	50854.6353	52103	51210.7110
47997	50887.5658	52775	51263.5436	47996	50887.5281	52749	51261.5375
48035	50890.5571	52788	51264.5672	48034	50890.5206	52774	51263.5082
48060	50892.5243	52800	51265.5091	48059	50892.4860	52787	51264.5305
48428	50921.4825	52813	51266.5330	48415	50920.5021	52800	51265.5536
48441	50922.5046	52838	51268.4989	48428	50921.5240	52825	51267.5196
51721	51180.6038	52851	51269.5229	51720	51180.5686	52838	51268.5443
51722	51180.6843			51721	51180.6516	52850	51269.4869
51747	51182.6512			51748	51182.7729	52851	51269.5667

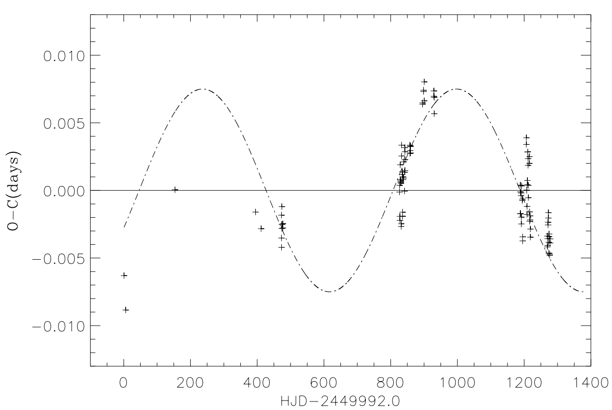

Fig. 4. $O-C$ diagram for V 1162 Ori, based on the times of maximum light of data from Hintz et al. (1998) and our y and b measurements, using a period of $0^d.078691216$ (Eq. (3)). The fitted sine has a period of 2.1 years.

the light–time effect, see e.g. Irwin (1959), we find that such values for the period and amplitude are not unreasonable for a low–mass companion, considering that one component (V 1162 Ori) has a mass of about $2M_{\odot}$. It is, however, clear that the $O-C$ behavior cannot be described by a truly cyclic function alone: in Fig. 4 large deviations from the fit are clearly present, and the $O-C$ variations must also have another cause than the light–time effect, if present at all. A much shorter period is also a possibility, but we do not find that we presently have enough data for a detailed analysis, and more data is needed over the coming years.

Due to the uncertainty in the count scheme following the period break found by Hintz et al. (1998), we have tried to modify the count scheme to see if all available data can be fitted with one single period, with cyclic variations superimposed. We have found that even then it is not possible to make a linear fit including the data from Poretti et al. (1990), i.e. the period break reported by Hintz et al. (1998) is real and cannot be ascribed to cyclic variations in the $O-C$ diagram.

In Fig. 5 we have collected the periods and amplitudes which have been determined for V 1162 Ori. From this figure, there seems to be no clear connection between the period and amplitude changes: whereas the 9–year gap between the second and the third point would suggest that the amplitude decreases with increasing period, the remaining data do not support such a correlation. The size of the period changes is of the order of $\Delta P/P \approx 10^{-4} - 10^{-5}$.

3.3. Phased light curves

We have used Eq. (1) to phase the light curves from January 1998, see Fig. 6. The mean magnitude in this plot is again from Hintz et al. (1998), as described in Sect. 3.1. In Fig. 7 we show a colour phase diagram from the same month, using the same

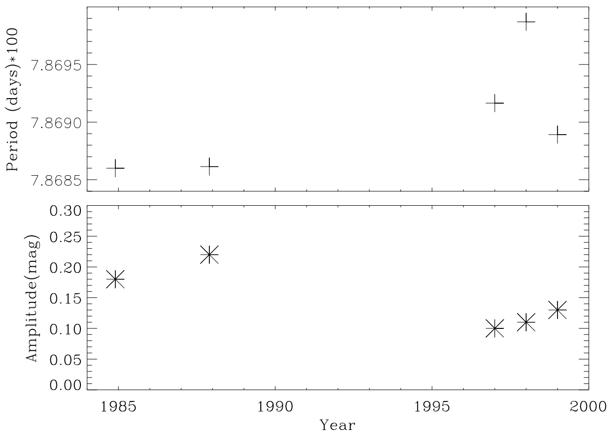

Fig. 5. The evolution of the pulsational period and amplitude (full light range) of V 1162 Ori with time. The error on each point is smaller than the plotted symbols. The first and second points are, respectively, from Lampens (1985) and Poretti et al. (1990), the third point is from Hintz et al. (1998), and the last 2 points are from this work.

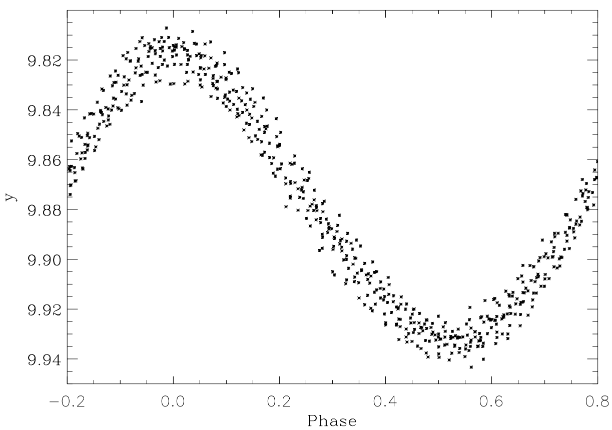

Fig. 6. Phased light curve for V 1162 Ori, based on Eq. (1) and data from January 1998.

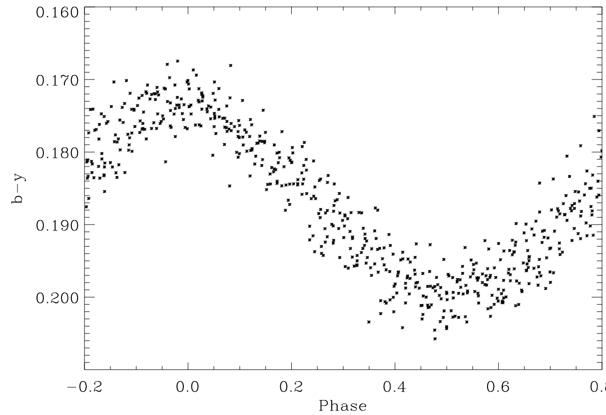

Fig. 7. Phased colour curve for V 1162 Ori, based on Eq. (1) and data from January 1998.

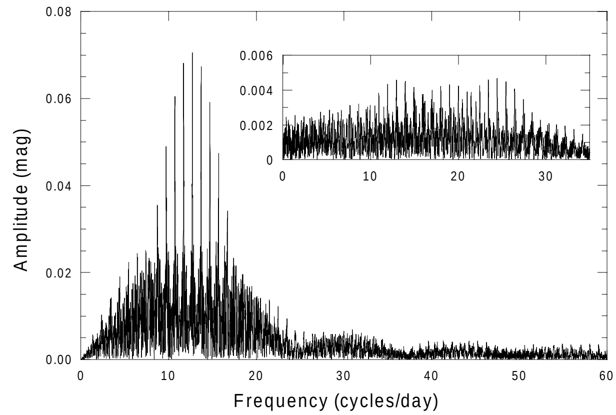

Fig. 8. Amplitude spectrum for V 1162 Ori, based on b-measurements from January, February and March 1998. The amplitude shown here is half the full light range. The insert shows the most significant section of the prewhitened amplitude spectrum (on a larger amplitude scale).

period. The $(b-y)$ curve given by Hintz et al. (1998) is not a smooth curve, but has a dented maximum. This is to some extent also the case in the second maximum of the colour curve in Fig. 2, while the phased colour curve is smooth.

It can be seen from Fig. 3 in Poretti et al. (1990) that the minimum in the phase diagram occurs after phase 0.5. This is also the case in our phase diagram shown in Fig. 6, and the light curves are thus not perfectly symmetric. From all our light curves, where we have both a maximum and a minimum, we have found the phase difference between a maximum and the following minimum to be $\Delta\phi = 0.524 \pm 0.019$ for the period Jan.–March 1998 (33 points), and $\Delta\phi = 0.554 \pm 0.029$ for the period April 1998–March 1999 (46 points).

3.4. Frequency analysis

We have also performed Fourier analysis of the time–series, in order to search for a possible second period. Because of the changes taking place, we had to split the data in two sets, one covering January–March 1998, and one covering April 1998 – March 1999. The amplitude spectra were calculated using the program *Period* (Breger 1990). The derived amplitude spectrum for the b-measurements of 1998 (January–March) is shown in Fig. 8. The formal resolution of the amplitude spectrum is 0.03 c/d, but the actual precision of the detected frequencies is higher than that. The main pulsation is clearly visible at a frequency of about 12.7 c/d. It is also clear from Fig. 8 that the spectral window function for these observations is poor. In early 1998, the full amplitude of the main pulsation, from the Fourier analysis, was $0\overset{m}{.}112$ in y and $0\overset{m}{.}138$ in b, and in 1999 $0\overset{m}{.}123$ in y and $0\overset{m}{.}152$ in b.

The periods determined from the two datasets (and in both y and b) were, within the errors, the same as the periods found from the $O-C$ analysis in Sect. 3.2.

After removing the main pulsation from the b time–series, we arrive at the residual spectrum shown as the insert in Fig. 8. Two structures with a highest peak of equal amplitude are now visible in the spectrum. The amplitude of both is about 4.5 mmag, which (at a noise level in the region of about 1.1 mmag) corresponds to a 4 σ detection. We do, however, find it doubtful that these peaks are due to real variations in the light curve. The highest peak in the structure around 25 c/d does not correspond to the $2f_1$ term, but it does, within the resolution, correspond to a 1 c/d alias. Assuming this structure is caused by the $2f_1$ term, this term will then have a half–amplitude of about 4.5 mmag, in agreement with Hintz et al. (1998). We do not find evidence of a second period at 16.48 c/d, as suggested by Hintz et al. (1998), and we can put an upper limit on the full amplitude of a possible second period at about 9 mmag. We must stress, however, that this does not rule out the presence of low–amplitude variations, which can have amplitudes much lower than this.

If the cyclic behavior of the $O-C$ diagram (Fig. 4) is caused by a beat between two very closely–spaced frequencies, it would be expected that an increase in amplitude for the main pulsation should lead to a decrease in the amplitude of the secondary pulsation. We do not see evidence for such a mechanism, and especially the dramatic decrease in amplitude (50 percent) between the studies of Poretti et al. (1990) and Hintz et al. (1998) can only be explained by a beat phenomenom if the two frequencies are so closely–spaced that they are non-resolved. However, if the period of the beat is 2 years, which we cannot be sure of from the present data, the secondary period would be so close to the primary that they would not be resolved in the observations presented here, covering a time base of about 500 days. A time base of at least 1000 days is in such a case needed to resolve the spectrum. A cyclicly changing period could cause a higher noise level in the amplitude spectrum, as seen in the prewhitened spectrum in Fig. 8. In this case, the Fourier analysis is no longer valid.

The noise level at high frequencies in the prewhitened spectrum is 0.24 mmag.

4. Conclusion

We have presented new yb photometric observations of V 1162 Ori, and we have shown that the star undergoes frequent period– and amplitude changes on a short time scale. The apparent abrupt nature of the period changes suggests a non–evolutionary origin. The cause of such period changes is presently not known, but it could be non–linear mode interactions (Breger & Pamyatnykh 1998). We do not see evidence for more than one pulsation mode, but this can be due to the noise level and the resolution in the amplitude spectrum.

A possible cyclic behavior of the period could be caused by a beat between two very closely–spaced frequencies, or by the presence of an orbiting object in a binary system.

Presently we do not have enough data to distinguish between the three possible solutions (a frequently changing period or a cyclic behavior due to either mode interactions or binarity). It seems certain that the previous period jump (Hintz et al. 1998) is real, and cannot be explained by a cyclic behavior.

The period– and amplitude changes observed in this star make it a highly interesting object. Further observations are crucial for understanding the observed changes. Our results indicate that such observations should not be restricted to short observing runs confined to one single site, but rather be distributed over the full observing season.

Acknowledgements. T.A. and C.S. acknowledge financial support from the Belgian Fund for Scientific Research (FWO).

This research has made use of the SIMBAD database operated at C.D.S., Strasbourg, France, and the NASA Astrophysics Data System. The authors are indebted to the referee, Dr. Ennio Poretti, for valuable comments which improved the manuscript.

References

Ai-Ying Z., Jian-Ning F., 1998, In: Breger M. (ed.) Delta Scuti Star Newsletter. Vol. 12, University of Vienna
Arentoft T., Sterken C., 1999, IBVS 4657
Breger M., 1990, Communications in Asteroseismology 20, 1 (University of Vienna)
Breger M., Pamyatnykh A.A., 1998, A&A 332, 958
Hintz E.G., Joner M.D., Kim C., 1998, PASP 110, 689
Irwin J.B., 1959, AJ 64, 149
Jian-Ning F., Shi-Yang J., 1996, IBVS 4325
Jønch–Sørensen H., 1994, A&AS 108, 403
Kjeldsen H., Frandsen S., 1992, PASP 104, 413
Lampens P., 1985, IBVS 2794
McNamara D.H., 1997, PASP 109, 1221
Petersen J.O., Høg E., 1998, A&A 331, 989
Poretti E., Antonello E., Le Borgne J.F., 1990, A&A 228, 350
Solano E., Fernley J., 1997, A&AS 122, 131
Sterken C., 1983, The Messenger 33, 10