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A photometric study of Be stars located in the seismology fields of COROT★

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ABSTRACT

Context. In preparation for the COROT mission, an exhaustive photometric study of Be stars located in the seismology fields of the mission has been performed. The very precise and long-time-spanned photometric observations gathered by the COROT satellite will give important clues on the origin of the Be phenomenon.
Aims. The aim of this work is to find short-period variable Be stars located in the seismology fields of COROT, and to study and characterise their pulsational properties.
Methods. Light curves obtained at the Observatorio de Sierra Nevada, together with data from Hipparcos and ASAS-3 for a total of 84 Be stars, were analysed in order to search for short-term variations. We applied standard Fourier techniques and non-linear least-square fitting to the time series.
Results. We found 7 multiperiodic, 21 mono-periodic and 26 non-variable Be stars. Short-term variability was detected in 74% of early-type Be stars and in 31% of mid- to late-type Be stars. We show that non-radial pulsations are more frequent among Be stars than in slow-rotating B stars of the same spectral range.

Key words. stars: emission-line, Be – stars: oscillations (including pulsations) – stars: statistics – techniques: photometric

1. Introduction

Be stars are non-supergiant B stars that show or have shown at one or another moment emission in Balmer lines. It is generally agreed that the origin of this emission is the presence of an equatorial circumstellar disk, fed by discrete mass loss events. For a complete review of the "Be phenomenon" and its properties, see Porter & Rivinius (2003).

Be stars show two different types of photometric variability, with different origins and time-scales. (i) Long-term variability due to variations in the size and density of the circumstellar envelope. Variations are irregular and sometimes quasi-periodic, with time-scales of weeks to years. In some stars, variations are in the form of outbursts with a total duration of weeks or months. (ii) Short-term periodic variability, with time-scales from 0.1 to 2 days, generally attributed to non-radial pulsations. Based on Hipparcos observations, Hubert & Floquet (1998) found that short-term variability is present in 86% of early Be stars, in 40% of intermediate sub-spectral types (B4e-B5e) and in only 18% of late Be stars. In the HR diagram, early Be stars are located at the lower border of the instability domain of the β Cephei stars, while mid and late Be stars are mixed with Slowly Pulsating B stars (SPB). Both β Cephei and SPB stars are main sequence pulsating B stars. Pulsations in β Cephei stars are caused by p-modes driven by the κ mechanism associated with the Fe bump, and have periods similar to the fundamental radial mode. SPB stars are g-mode pulsators with periods longer than the fundamental radial one. Therefore, short-period p-modes are expected in early Be stars and long-period g-modes in mid to late Be stars.

Recently, the high-precision photometric data obtained with the MOST satellite has revealed a rich spectrum of frequencies associated with radial and non-radial pulsations in three Be stars, namely ζ Oph (O9.5Ve, Walker et al. 2005b), HD 163868 (B5Ve, Walker et al. 2005a) and β CMi (B8Ve, Saio et al. 2007). This discovery suggests that pulsations are present in all rapidly rotating Be stars.

The characterisation of the short-term variability in Be stars is essential for the understanding of the Be phenomenon. The spectroscopic analysis led by Rivinius et al. (2001) in μ Cen suggested that non-radial pulsations combined to the near break-up rotational velocity are probably the mechanism responsible for the mass ejection. However, μ Cen is, up to now, the only known Be star that presents this behaviour. The observation of Be stars with the COROT satellite will provide photometric time series with an unprecedented quality that will allow us to perform a deep study in the role of non-radial pulsations and its relation with the Be star outbursts.

The French led COROT satellite[1] was successfully launched on 27 December 2006 and started its scientific observations on

★ Appendix A is only available in electronic form at http://www.aanda.org

[1] http://corot.oamp.fr/

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3 February 2007. COROT has two main goals: the study of the stellar interiors by looking at their oscillations and the search for exoplanets by detecting planetary transits (see Baglin et al. 2002). In each pointing, up to 10 stars with magnitudes between 5.5 and 9.4 will be monitored in the two CCDs of the seismology program during 150 or 20 days with a photometric precision of ∼1 ppm. The COROT telescope will be pointed alternatively in the direction of two regions in the sky, placed at the intersection between the equator and the Galactic plane. Both regions have a radius of 10 degrees and are denoted as the centre and anticentre cones, respectively, regarding their positions relative to the Galactic centre.

Bright Be stars will therefore be observed as secondary targets of the asteroseismology program. An international collaboration (The COROT Be stars team[2]) led by A.-M. Hubert has studied the bright Be stars candidates to be observed by COROT. In this framework, Neiner et al. (2005) identified 16 previously unknown Be stars in the COROT observing cones, Frémat et al. (2006) determined the fundamental parameters of 64 Be stars in the regions, and Gutiérrez-Soto et al. (2007) found two of them to be multiperiodic and characterised their pulsational behaviour.

The aim of this work is to characterise the short-term photometric variability of all bright Be stars located in the COROT cones, which are suitable to be observed in the seismology fields. In addition, we have investigated the pulsational properties of Be stars and their degree of variability with respect to other pulsating B stars.

2. Observations and data analysis

2.1. The sample

A total of 84 Be stars have been found in the observing cones of COROT with magnitudes ranging from 5.5 to 9.4. The list has been taken from Jaschek & Egret (1982), complemented with the new Be stars identified by Neiner et al. (2005).

Due to the high number of stars to be analysed, a selection criterion was made. As a first step, all of the stars close to the primary targets of COROT were observed during a 4-year campaign at the Observatorio de Sierra Nevada (OSN); these were selected as they have the highest probability of being observed by the satellite. As the decision for the exact position of the CCDs was finally made by the scientific committee of COROT in 2006, we observed some Be stars whose locations are distant from the finally selected primary targets. Be stars whose results did not lead to a convincing period determination during the observing run were re-observed at the OSN and re-analysed. In addition, the Hipparcos and ASAS-3 light curves of all Be stars in the COROT cones were analysed in order to complement the study performed with the OSN data.

The studied stars with their spectral types and $V \sin i$ are reported in Tables A.1 and A.2 (available only in electronic form at `http://www.aanda.org`).

2.2. Observatorio de Sierra Nevada (OSN)

Ground-based observations were obtained at the 0.9 m telescope of the OSN in Granada, Spain, from 2002 to 2006. We used the automatic four-channel spectrophotometer, which allows simultaneous observations through the four *uvby* filters of the Strömgren system. Obtaining photometric light curves in four filters at the same time allows us to confirm or reject uncertain periods. Only frequencies detected simultaneously in the *vby* filters are considered as certain, as the signal to noise for the *u* filter is significantly lower.

Dates of the observing runs and observing nights are reported in Table 1. We applied three-star differential photometry, similar to the one described by Lampens et al. (2005); a variable, a comparison, a check star and the appropriate sky background were measured successively (sky – var – comp – check – sky – var . . .). Usually, we observed up to 8 target stars every night and we repeated the measurements for each night. It was only in the winter 2003 that we devoted each clear night to survey an individual star.

Sky level and mean extinction coefficients were obtained for each night. 24 Be stars were observed at the OSN in the anticentre and the centre directions. These Be stars, with the corresponding comparison and check stars, are presented in Tables A.1 and A.2, respectively. A few comparison stars were found to be low-amplitude variables, as for example, HD 171 305 and HD 182 786 (Gutiérrez-Soto et al., in preparation).

The mean accuracy of the differential photometry, measured as the standard deviation of the difference between the comparison and check values for the whole campaign, is, in all cases, less than 10 mmag in *u* and 7 mmag in *vby*, as shown in Table 1.

Table 1. Summary of observing nights at the OSN. The mean accuracy of each dataset is also provided (see text for details).

Dates	Observing nights	Accuracy (mmag) *u*	*v*	*b*	*y*
20–29 May 2002	10	10	6	6	7
8–14 Jan. 2003	4	9	4	3	4
1–13 Jul. 2003	9	8	4	4	6
30 Jan.–8 Feb. 2004	4	10	5	5	6
13–24 Jul. 2005	6	10	5	5	5
16–30 Jan. 2006	5	7	4	4	5

2.3. Hipparcos

Hipparcos (High Precision Parallax COllecting Satellite, Perryman et al. 1997) was an astrometric mission of the European Space Agency dedicated to the measurement of positions, parallaxes and proper motions of stars. As a by-product of the astrometric mission, stellar magnitudes were repeatedly measured for each star on numerous occasions throughout the mission, resulting in an enormous collection of light curves. Hubert & Floquet (1998) showed that Hipparcos is a useful tool for the study of variability of bright Be stars. A total of 62 stars located in the observing cones of COROT were observed by Hipparcos. An average of 100 datapoints spanning 1000–1100 days are provided for each observed star. The standard error of a measurement ranges from 6 mmag for stars with magnitude 6 to about 17 mmag for stars with magnitude 9.

2.4. ASAS-3

The All Sky Automated Survey (ASAS, Pojmanski 2002) is a project whose final goal is photometric monitoring of approximately 10^7 stars brighter than 14 mag. ASAS-3 is the third stage of the ASAS project, which has surveyed the whole of the southern and part of the northern sky. We have analysed the light curves of 50 Be stars fainter than 7.8 located in the observing cones of COROT. Stars brighter than 7.8 were not considered as

[2] `http://www.ster.kuleuven.ac.be/~coralie/corotbe.html`

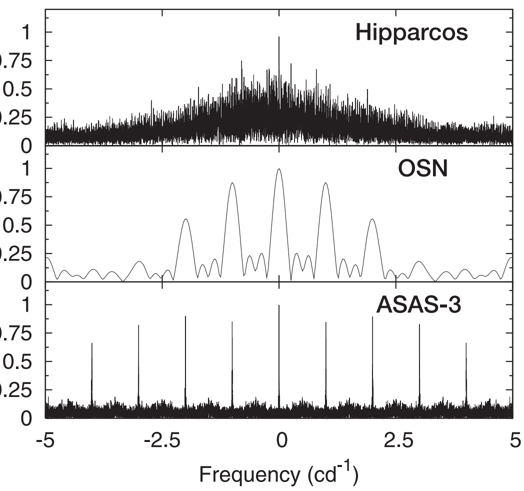

Fig. 1. An example of a spectral window for the three instruments used in this paper.

they most likely saturate the detector. An average of 200 datapoints spanning over 1700 days are provided for each star. Since five different magnitudes, depending on the aperture radius, are provided, we have selected the one that produces the least error, usually the 4th and 5th aperture in our case. Only measurements with quality grade A were analysed. Errors of the ASAS-3 photometry range from 10 to 25 mmag for the studied stars.

2.5. Frequency analysis

Frequency analysis was applied to the time series of each star in the three datasets separately. In some cases, we were able to combine OSN and ASAS datasets in order to refine the detected frequencies.

We employed the Period04 program (Lenz & Breger 2005), which searches for frequencies by means of standard Fourier analysis. Once a frequency is detected, the program adjusts the parameters of a sinusoidal function using a least-square fitting and prewhitens the signal from this frequency. Then, a new frequency is found in a new step, and the subsequent least-square fitting is performed, allowing the two frequencies to move in order to get the minimum variance. The method is iterative and stops when the removal of a new frequency is not statistically significant.

We also used a non-linear multi-parameter fitting code, which scans a wide range in frequency, based on Vaníček (1971) and explained in detail in Zerbi et al. (1997). This code is well-suited for the OSN and ASAS-3 data, for which daily aliases are present in the periodogram, due to the fact that the observations were obtained at only one site. We have to note here that the final frequency solution for the OSN and ASAS-3 data can be contaminated from 1 c d^{-1} aliases.

In Fig. 1 we show an example of a spectral window for the Hipparcos, OSN and ASAS data. The non-random distribution in time of the Hipparcos photometry produces a spectral window that is very complex. In the case of the OSN and ASAS-3 observations, a 1-day alias pattern is present in the spectral window. Note the different widths of the sidelobes, depending on the time length of the observations.

We accept frequencies as long as they fulfil the signal-to-noise ratio (SNR) criterion described in Breger et al. (1993). Kuschnig et al. (1997) demonstrated that a level in the amplitude spectrum of 4 times the noise level will include 99.9% of all the peaks due to noise. The noise level is computed by averaging the amplitude within a 5 c d^{-1} frequency interval of the residual periodogram after final prewhitening.

For the determination of the error in frequencies, we follow equations given by Montgomery & O'Donoghue (1999), taking into account the correlations in the residuals of the fitting (Schwarzenberg-Czerny 1991). We obtained frequency errors of $2{-}4 \times 10^{-3}$, $3{-}4 \times 10^{-5}$ and $1{-}2 \times 10^{-5}$ for the OSN, Hipparcos, and ASAS-3 datasets, respectively. The frequency resolution is given by $1/T$, where T is the time length of the observations. In our case, we estimate 0.1 c d^{-1}, 0.001 c d^{-1} and 0.0006 c d^{-1} for the OSN, Hipparcos and ASAS-3 observations, respectively.

2.6. Results

Results of the data analysis are summarised in Tables 2 and 3, where we present the frequencies found for all stars analysed for short-term variability. In the few cases in which we obtained different results from different datasets, we considered the one from the instrument with higher precision to be more reliable. Therefore, frequencies obtained from the OSN data are considered as the most reliable, followed by those found from the Hipparcos and ASAS-3 datasets.

Mid- and long-term variability is often present in the light curves of Be stars. In some cases, it shows a complex pattern that prevents the study of the short-term variability. In addition, the data for some stars present a bad sampling or too few datapoints in the light curve. For these reasons, we were not able to perform short-period analysis for some stars in our sample. They are marked with the "–" symbol in Tables 2 and 3.

Stars showing short-term variability, with peak to peak amplitudes higher than 0.04 mag during several days, are considered as variable, even if we were not able to determine the frequency. For other stars, the analysis performed in this work yields uncertain frequencies. These stars are marked in Tables 2 and 3 with the symbols "var" and "?", respectively.

Short-term variability analysis was finally performed on 57 bright Be stars in the COROT cones. 31 were found to be variable and 26 non-variable at the detection level of the instruments. Multiperiodic variability was found in seven stars. Notes on the individual stars are presented in Appendix A, only available in the electronic edition of the paper.

3. Discussion

In Fig. 2 we show the position in the HR diagram of the stars for which we performed short-term variability analysis. The physical parameters were accurately obtained for only 41 Be stars from this sample. Values of $\log L/L_{\odot}$ and $T_{\rm eff}$ of all stars but one are taken from Frémat et al. (2006), assuming $\Omega/\Omega_{\rm c} = 0.9$, which is the average angular velocity rate of Galactic field Be stars (Frémat et al. 2005). For the star HD 48282, the spectral parameters are taken from the paper by Levenhagen & Leister (2004). For comparison, we have also plotted the theoretical boundaries of the β Cephei and SPB instability strips from Pamyatnykh (1999).

We investigate the degree of short-term variability in our sample of Be stars. We have distinguished between early (B0−B3) and mid- to late-type Be stars (B4−B9). In the case of pulsating B-type stars, the first interval is occupied by β Cephei variables and the hottest SPB stars. According to Pamyatnykh (1999), the hot-temperature boundary computed with OPAL opacities takes place at B3 (see Fig. 2), but if

Table 2. Results of the photometric study for stars in the Galactic anticentre direction. Frequencies in c d^{-1} are shown for the Hipparcos, OSN and ASAS-3 datasets. The "–" stands for stars for which a short-period analysis could not be performed. The "*" stands for stars that were not observed with the instrument. The "**" stands for stars that are saturated in the ASAS-3 database. The "var" stands for stars showing short-term variability but not periodicity. The "no var" stands for stars that do not show short-term variations at the detection level of the instrument. The "?" stands for frequencies that are uncertain. For details, see text. In the last column some complementary indications and/or frequencies detected by other authors are given: (1) stars included in the ASAS-3 catalogue of variable stars (Pojmanski 2002); (2) Neiner et al. (2005); (3) Hubert & Floquet (1998); (4) Gutiérrez-Soto et al. (2007); (5) Lynds (1960); (6) Percy et al. (2002).

Be star	Hipparcos	OSN	ASAS-3	Remarks
HD 42259	var	1.28	1.3223 + 0.7401	
HD 42406	–	*	no var	
HD 43264	–	*	**	
HD 43285	2.203/6.173?	no var	**	
HD 43777	–	*	no var	
HD 43913	–	*	no var	
HD 44783	–	*	**	
HD 45260	var	*	–	
HD 45626	*	*	–	
HD 45901	0.466	*	–	
HD 45910	–	*	**	
HD 46380	–	1.75 ?	–	
HD 46484	–	2.45	**	
HD 47054	no var	*	**	
HD 47160	–	*	**	
HD 47359	*	*	–	
HD 47761	–	*	–	
HD 48282	–	*	0.6819	
HD 49330	3.534	2.129	–	(1)
HD 49567	0.39	*	**	0.39 (2)
HD 49585	*	1.65 + 1.21	–	(1)
HD 49787	–	*	**	
HD 49992	*	*	var	
HD 50083	–	*	**	
HD 50087	–	no var	no var	
HD 50209	1.689/1.47	1.4889	2.4803+1.4749	
HD 50424	*	*	–	
HD 50581	no var	*	**	
HD 50696	*	3.22	–	
HD 50820	no var	*	**	
HD 50868	–	*	no var	
HD 50891	*	1.88	–	(1)
HD 51193	1.639	2.66	1.606	
HD 51404	*	2.68 + 5.99	var	
HD 51452	*	1.58 ?	no var	
HD 51506	–	*	**	
HD 53085	–	*	**	
HD 53367	–	*	**	
HD 54464	*	*	–	
HD 55135	–	*	**	
HD 55439	–	*	–	
HD 55606	*	*	no var	
HD 55806	–	*	no var	
HD 57386	–	*	no var	
HD 57539	–	*	**	
HD 259431	–	*	no var	
HD 259440	*	*	no var	
HD 259597	*	*	no var	
HD 293396	*	*	–	

OP opacities are used, g-modes are excited even in stars much hotter than B3. Pulsating B stars in the B4−B9 interval are only SPB stars. In addition, this distinction between early- and late-type Be stars has also been considered by other authors (e.g. Hubert & Floquet 1998) for phenomenological reasons: pulsations are frequent in the early-type interval and scarce in the late-type one.

We found that short-term variability is present in 74% of early-type Be stars and 31% of mid- to late-type Be stars (see Fig. 3). The results presented here are similar to those obtained by Hubert & Floquet (1998), from a larger sample of Be stars observed by the space mission Hipparcos.

In order to compare the degree of variability of Be stars with respect to slow-rotating B-type stars, we searched in the literature for the fraction of β Cephei and SPB stars among the total number of B stars in their spectral ranges. To our knowledge, general studies of these fractions have not been undertaken. For this reason, we studied the fraction of β Cephei and SPB stars in

Table 3. Same as for Table 2, but for stars in the Galactic centre direction.

Be star	Hipparcos	OSN	ASAS-3	Remarks
HD 166917	no var	*	**	
HD 168797	2.049	1.20+1.13+3.30+1.41.	**	2.049 (3); 1.20+1.13+3.30+1.41 (4)
HD 170009	no var	*	*	
HD 170714	–	3.79	**	
HD 171219	no var	no var	**	
HD 173219	var	*	**	
HD 173292	var	*	0.6824	
HD 173371	no var	*	**	
HD 173530	*	*	1.3703	
HD 173637	–	1.86	–	(1)
HD 173817	no var	3.51 ?	no var	
HD 174512	0.82	*	no var	0.82 (2)
HD 174513	–	3.34	0.0271 + 5.293	
HD 174571	–	*	–	
HD 174705	*	*	2.3164	
HD 174886	no var	*	**	
HD 175869	no var	*	**	
HD 176159	–	*	no var	
HD 176630	1.59	*	**	1.59 (2)
HD 178479	–	*	–	
HD 179343	–	*	**	
HD 179405	var	1.62+2.78+2.56+1.27	–	1.62+2.78+2.56+1.27 (4)
HD 180126	–	*	–	
HD 181231	no var	0.67?	3.4304?	
HD 181308	*	*	–	
HD 181367	*	no var	no var	
HD 181709	no var	*	no var	
HD 181803	–	*	–	
HD 183656	1.534	3.63	**	1.534 (3);1.1739 (5)
HD 184203	*	*	–	
HD 184279	6.410 ?	var	**	(1); 1.667 (6)
HD 184767	–	*	**	
HD 194244	no var	*	**	
HD 230579	*	*	no var	
BD-094858	*	*	–	

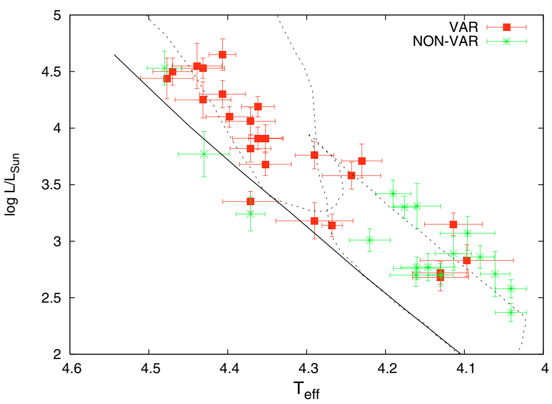

Fig. 2. Location of the studied Be stars in the theoretical HR diagram. Red filled squares correspond to variable stars and green asterisks to non-variable stars. The solid line represents the ZAMS from Schaller et al. (1992) and the dashed lines describe the theoretical β Cephei and SPB instability strips computed by Pamyatnykh (1999).

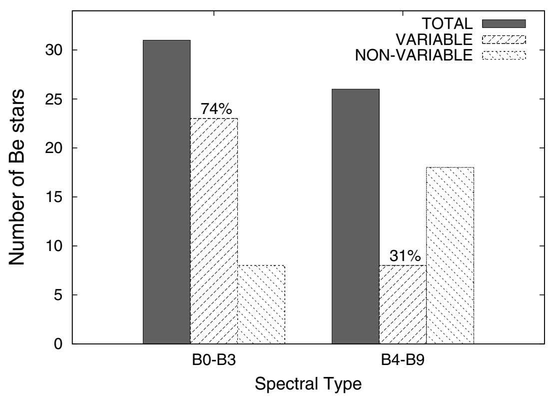

Fig. 3. Distribution of short-term variability as a function of spectral type for stars in our sample.

a sample of Galactic field stars observed by the Hipparcos mission. Our sample consists of all stars in the Bright Star Catalogue (Hoffleit & Jaschek 1991) with spectral type between B0 and B9 and luminosity class V-III, whose Hipparcos parallax has an accuracy better than 20% and with Strömgren photometry in the catalogue of Hauck & Mermilliod (1998). All known Be stars were excluded from the sample. The whole sample consists of 185 stars in the B0−B3 spectral domain and 610 in the B4−B9 domain. The Hipparcos photometry of all these stars has been searched for short-term variability (Eyer 1998; Waelkens et al. 1998). The results of these surveys together with previous literature are included in the most recent lists of known β Cephei (Stankov & Handler 2005) and SPB stars (de Cat 2002).

Among the 185 stars in the early spectral domain, 16 are catalogued as β Cephei and 14 as SPB stars, considering both confirmed and candidate SPB stars as listed by de Cat (2002).

This amounts to a total of 30 pulsating stars, representing the 16% of the sample. For stars in the B4−B9 range, 21 are listed as confirmed and candidate SPB stars. This represents a fraction of 3.4%. The photometric data and the variability search techniques for this sample are the same as used by Hubert & Floquet (1998) for their short-term variability study of Be stars observed by Hipparcos, and hence the results of both searches are directly comparable.

In addition, we searched in the literature for photometric surveys aimed to detect pulsating B stars in the population of Galactic open clusters that are young enough to have their B-star main sequence complete. A cluster population cannot be considered as representative of the Galactic field as it is composed of stars in a very narrow range of ages and metallicities. However, by taking into account the mean results for several clusters with different astrophysical parameters, we can consider them representative.

The number of β Cephei and SPB stars in clusters were taken from the studies of Krzesinski & Pigulski (1997) for NGC 884, Krzesiński et al. (1999) for NGC 869, Pigulski et al. (2001) for NGC 663, Balona (1994) for NGC 3293, Balona & Koen (1994) for NGC 4755, Balona & Laney (1995) and Arentoft et al. (2001) for NGC 6231, and Balona & Laney (1996) for NGC 2362. In order to select the B stars in the B0−B3 and B4−B9 spectral ranges, we used Strömgren *uvby* photometry from Capilla & Fabregat (2002) for NGC 884 and NGC 869, Fabregat & Capilla (2005) for NGC 663, Balona (1994) for NGC 3293, Balona & Koen (1994) for NGC 4755, Balona & Laney (1995) for NGC 6231, and Balona & Laney (1996) for NGC 2362.

Stars within the two ranges were selected by using the reddening-free indices [c1] and [m1] and their relationship with spectral types given by Moon (1986). Known Be stars were removed from the final list.

In Table 4 we show the percentage of β Cephei in the studied open clusters. An average percentage of around 13.5% is found for β Cep stars. Note that the dispersion is quite high, although it is already known that clusters with similar age have very different proportion of β Cephei stars (Balona et al. 1997). The number of SPB stars found in the above clusters is too low to allow any reliable statistics.

The fraction of early-type pulsating B stars is 16% and 13.5% from the Galactic field and cluster stars, respectively. These values are significantly lower than the percentage of pulsating Be stars with spectral types between B0 and B3, which is 74% from the present work, and 86% from the Hipparcos sample studied by Hubert & Floquet (1998). The fraction of SPB stars in our late-type B stars sample is 3.4%, again significanly lower than the value of 31% found for late-type Be stars in our sample and 26% found by Hubert & Floquet (1998). We can conclude that the fraction of non-radial pulsators among fast-rotating Be stars is much higher than the fraction among slow-rotating B stars of the same spectral type.

One of the most remarkable characteristics of Be stars is the high rotational velocity. In this context, the above results suggest that high-rotational velocity may have the effect to trigger the development of non-radial pulsations in B stars, or to enhance the amplitude of existing modes to make them more easily detectable. Alternatively, the higher prevalence of non-radial pulsations could be related to other ingredients of the yet unknown nature of the Be phenomenon.

A deeper exploration of the physical implications of these results is not yet possible, due to the lack of adequate models describing the stellar pulsations at rotational velocities close to the critical. However, we consider that these results constitute a valuable input for the models being currently developed (e.g. Reese et al. 2006).

Table 4. Percentage of β Cephei stars among the number of B stars in the same spectral range for different open clusters.

Cluster	% β Cep
NGC 884	12–14%
NGC 869	5–7%
NGC 663	9–12%
NGC 3293	25%
NGC 4755	25–30%
NGC 6231	10–15%
NGC 2362	0%

4. Conclusions

We have studied the short-term variability of 57 bright Be stars located in the seismology fields of COROT. We have analysed *uvby* photometry obtained at the OSN together with data from the Hipparcos mission and ASAS-3 project. 31 stars were detected as variable and 26 were considered as non-variable at the detection level of the instruments. Moreover, seven variable stars were found to be multiperiodic.

We have shown that non-radial pulsations are more frequent in Be stars than in slow-rotating B stars of the same spectral range. These results allow us to suggest that high-rotational velocity can either contribute to trigger the development of non-radial pulsations or to enhance the amplitude of the existing modes. As an alternative explanation, the prevalence of non-radial pulsations could be related to the yet unknown nature of the Be phenomenon.

The observations of Be stars with the COROT satellite, currently underway, will help to answer these issues and serve as input to the elaboration of pulsational models for high-rotating stars, which are currently being developed.

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Online Material

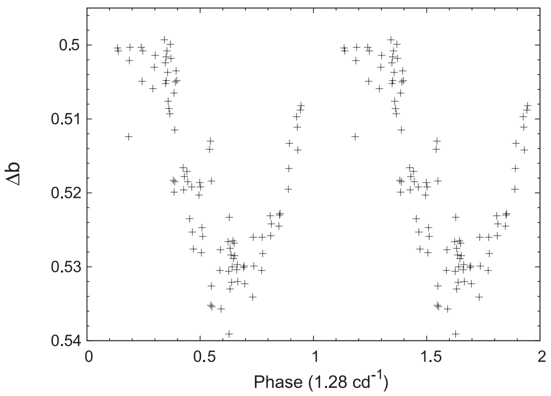

Fig. A.1. Light curve of the star HD 42259 folded in phase with the frequency 1.28 c d^{-1}, for the OSN data in the v filter.

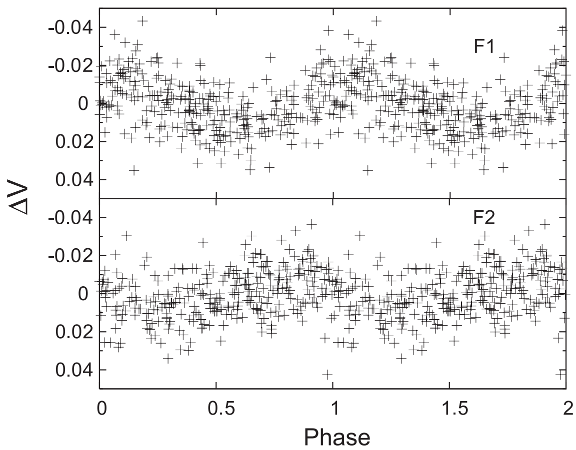

Fig. A.2. Light curve of the star HD 42259 folded in phase with the frequency $F1$ = 1.3223 c d^{-1} for the ASAS-3 dataset (*top*) and with the frequency $F2$ = 0.7401 c d^{-1} for the residuals after prewhitening for $F1$ (*bottom*).

Appendix A: Notes on individual stars

Here, we present some notes on all the Be stars observed at the OSN and the Be stars that showed periodicity in the ASAS-3 or Hipparcos light curve. For a detailed study of stars HD 168797 (NW Ser) and HD 179405 (V1446 Aql), see Gutiérrez-Soto et al. (2007). We have divided the sample into stars located in the Galactic centre and anticentre directions.

A.1. Stars in the Galactic anticentre direction

A.1.1. HD 42259

The Hipparcos light curve shows variability with an amplitude from peak to peak of 6 hundredths of magnitude.

We observed this star in 2006 at the OSN. The amplitude of the light curve varies from night to night, suggesting the presence of multiperiodicity. Strong peaks appear in the periodogram of the v filter at frequency 1.28 c d^{-1} and its 1-day aliases. Results with the by filters are similar within errors. A phase plot with this frequency is displayed in Fig. A.1. A frequency at 1.41 c d^{-1} also has a good fit and a good phase diagram. The time span of the observations does not allow us to distinguish between these two frequencies.

In the analysis of the ASAS-3 dataset, we find a frequency at $F1$ = 1.3223 c d^{-1} (Fig. A.2, upper panel), which is similar within errors to the one detected at the OSN. After prewhitening for this frequency, we find another significant frequency at $F2$ = 0.7401 c d^{-1}. The 1-day alias $F2'$ = 1.2626 c d^{-1} also gives a similar fit, although $F2$ has a less scattered phase diagram (Fig. A.2, bottom panel).

A.1.2. HD 43285

Peaks at frequencies 2.203 and 6.173 c d^{-1} are detected in the Hipparcos data, although the resulting phase diagrams are very scattered.

We only observed this star during one season in 2003 at the OSN. Our light curve spanning 9 h does not show any sign of variation at any frequency with an amplitude exceeding 2 mmag in the vby filters and 3 mmag in the u filter. This star is saturated in the ASAS-3 database.

A.1.3. HD 45901

This star was only observed with Hipparcos and ASAS-3. A long-term trend is present in the Hipparcos light curve. After prewhitening for this trend, significant peaks at frequencies 0.548 c d^{-1} and 0.466 c d^{-1} are clearly detected in the periodogram. The less scattered phase diagram is obtained with frequency 0.466 c d^{-1}, which is shown in Fig. A.3.

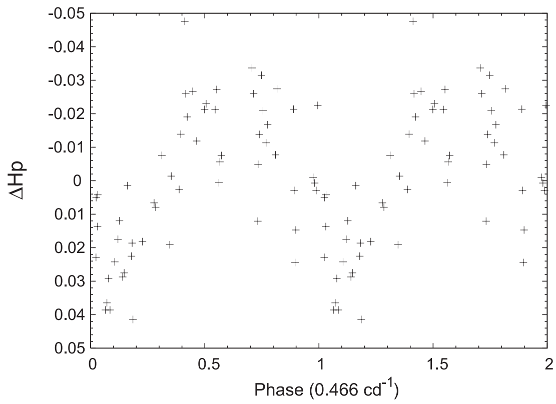

Fig. A.3. Light curve of the star HD 45901 folded in phase with the frequency 0.466 c d^{-1} for the Hipparcos dataset.

The ASAS-3 data show a long-term variation that is too complicated to be modelled, which prevents us to search for short-term variability in this dataset.

A.1.4. HD 46380

The Hipparcos light curve shows mid- and long-term variability, which does not allow us to search for short-term periodicity.

The photometric observations collected at the OSN extend over two seasons, 2003 and 2006. The 2003 dataset confirms the variability of the star. A frequency of 3.49 c d^{-1} appears clearly in the periodogram, although it is very uncertain, due to the short time coverage (6 h). The light curve obtained in 2006 shows clear variability at frequency 1.75 c d^{-1} in all filters. The phase diagram for this frequency is very scattered, due to the fact that the amplitude of the signal is 3 mmag. Note that the frequency obtained in 2003 is twice the frequency found in 2006. The light curve obtained in 2006 has been folded in phase with the frequency 3.49 c d^{-1}, with a negative result. More observations are required to confirm the detected frequency.

Table A.1. Studied Be stars in the Galactic anticentre direction. ID numbers and SIMBAD V magnitudes are given for each target in Cols. 1 and 2. The spectral type and $V \sin i$ are gathered in Cols. 3 and 4. Comparison and check stars used for the differential photometry are given in Cols. 5 and 6. References of the spectral type and $V \sin i$ are given in Col. 7. References: (1) Frémat et al. (2006); (2) Simbad database.

Be star	V	Sp. type	$V \sin i$ km s^{-1}	Comp.	Check	References
HD 42259	8.89	B0V		HD 294788	HD 42369	2
HD 42406	8.0	B4IV	300			1
HD 43264	6.05	B9III	284			1
HD 43285	6.05	B5IV	274	HD 44783	HD 43526	1
HD 43777	7.8	B5				2
HD 43913	7.88	A0				2
HD 44783	6.23	B9II	227			1
HD 45260	9.04	B8				2
HD 45626	9.25	B7				2
HD 45901	8.85	B0.5IV	173			1
HD 45910	6.74	B2III				2
HD 46380	8.05	B1.5IV	310	HD 46541	HD 46519	1
HD 46484	7.65	B0.5IV	130	HD 46106	HD 46748	1
HD 47054	5.52	B7III	229			1
HD 47160	7.10	B8IV	158			1
HD 47359	8.87	B0IV	469			1
HD 47761	8.72	B2V	50			2
HD 48282	8.79	B3V	188			2
HD 49330	8.95	B0.5IV	285	HD 50086	HD 50230	1
HD 49567	6.15	B3III	94			1
HD 49585	9.13	B0.5IV	325	HD 50086	HD 50230	1
HD 49787	7.55	B1V	169			1
HD 49992	8.98	B1				2
HD 50083	6.91	B2III	193			1
HD 50087	9.08	B8III		HD 50086	HD 50230	2
HD 50209	8.36	B8IV	209	HD 50086	HD 50230	1
HD 50424	8.92	B9				2
HD 50581	7.54	A0IV	250			1
HD 50696	8.87	B1.5III	366	HD 50086	HD 50230	1
HD 50820	6.27	B3IV				2
HD 50868	7.87	B1.5V	276			1
HD 50891	8.88	B0.5V	231	HD 50348	HD 51150	1
HD 51193	8.06	B1.5IV	224	HD 50348	HD 51150	1
HD 51404	9.30	B1.5V	353	HD 50348	HD 51150	1
HD 51452	8.08	B0IV	309	HD 50348	HD 51150	1
HD 51506	7.68	B2.5IV	186			1
HD 53085	7.21	B4IV	222			1
HD 53367	6.97	B0IV	70			2
HD 54464	8.4	B2.5III	177			1
HD 55135	7.34	B2.5V	264			1
HD 55439	8.47	B2				2
HD 55606	9.04	B0.5V	361			1
HD 55806	9.11	B7III	202			1
HD 57386	8.0	B1.5V				2
HD 57539	6.6	B5III	155			1
HD 259431	8.71	B6	95			2
HD 259440	9.12	B0	430			2
HD 259597	9.33	B1V				2
HD 293396	8.59	B1V				2

The ASAS-3 light curve shows a long-term trend, which does not allow us to search for short periods.

A.1.5. HD 46484

This star was detected as a spectroscopic variable by Hubert (priv. comm.). No results were obtained from the Hipparcos data, due to the bad sampling of the data and the few observed points.

Our 4-day light curve obtained in 2004 at the OSN shows variability with an amplitude of the order of 5 mmag. A frequency at 2.45 c d^{-1} and its 1-day aliases appear in the periodogram of the *vby* light curves. The phase diagram of the *b* light curve folded with the frequency 2.45 c d^{-1} is presented in Fig. A.4. This star is saturated in the ASAS-3 database.

A.1.6. HD 48282

A long-term trend is present in the light curve of Hipparcos and ASAS-3, which has been removed with a low-order polynomial. No results were found with the Hipparcos data. The frequency analysis of the ASAS-3 dataset yields a main variation at 0.6819 c d^{-1}. The corresponding phase diagram (Fig. A.5) is

Table A.2. The same as for Table A.1, but for the stars in the Galactic centre direction.

Be star	V	Sp. type	$V \sin i$ km s^{-1}	Comp.	Check	References
HD 166917	6.69	B8III	173			1
HD 168797	6.14	B2.5III	279	HD 170200	SAO 123607	1
HD 170009	8.00	B2.5III	181			1
HD 170714	7.38	B1.5IV	280	HD 171305	HD 169581	1
HD 171219	7.65	B5III	314	HD 170200	SAO 123607	1
HD 173219	7.82	B0.5IV	66			1
HD 173292	8.60	B8				2
HD 173371	6.89	B7IV	295			1
HD 173530	8.87	B7III	246			1
HD 173637	9.29	B1IV	207	HD 173693	HD 173850	1
HD 173817	8.65	B6IV	276	HD 172868	HD 173422	1
HD 174512	8	B8				2
HD 174513	8.70	B1.5IV	261	HD 174395	HD 174650	1
HD 174571	8.89	B1.5V	250			1
HD 174705	8.34	B1.5IV	341			1
HD 174886	7.77	B4III	79			1
HD 175869	5.56	B8III	171			1
HD 176159	8.98	B5IV	243			1
HD 176630	7.70	B3III	188			1
HD 178479	8.92	B3V	109			1
HD 179343	6.94	B8III	155			1
HD 179405	9.12	B2IV	248	HD 179846	HD 178598	1
HD 180126	8.00	B2IV	252			1
HD 181231	8.58	B5IV	259	HD 182198	HD 182786	1
HD 181308	8.70	B5IV	261			1
HD 181367	9.36	B6IV	292	HD 182198	HD 182786	1
HD 181709	8.79	B6III	291			1
HD 181803	9.10	B7III	190			1
HD 183656	6.09	B6V	270	HD 183227	HD 183563	2
HD 184203	9.16	B9				2
HD 184279	6.98	B0V	137	HD 183227	HD 183563	1
HD 184767	7.18	A0III	49			1
HD 194244	6.14	B9III	232			1
HD 230579	9.10	B1IV	343			1
BD -094858	8.84	B1.5V	115			1

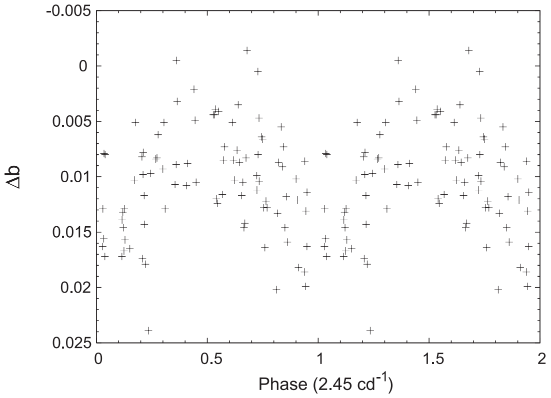

Fig. A.4. Phase diagram of HD 46484 folded with the frequency 2.45 c d^{-1} for the OSN data in the b filter.

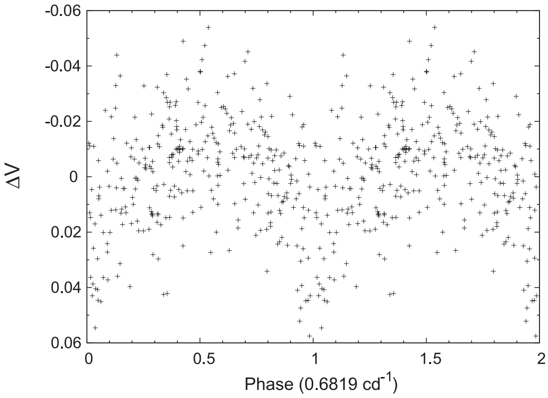

Fig. A.5. Phase diagram of HD 48282 folded with the frequency 0.6819 c d^{-1} for the ASAS-3 data.

very scattered, probably due to the presence of the long-term trend.

A.1.7. HD 49330

The Hipparcos data show a clear periodicity of 0.283 d, i.e. at frequency 3.534 c d^{-1}.

This star was observed at the OSN during three observing runs, in 2003, 2004 and 2006. In 2003, our 8.5-h light curve presents clear variability. The short-time coverage does not allow us to perform a period search. In 2004, our 4-day light curve does not show this variation. Only peaks at $1, 2, \ldots$ c d^{-1} are present in the periodograms of each filter, with an incoherent phase diagram. In 2006, a frequency at 1.15 c d^{-1} and its 1-day aliases strongly appear in the periodogram.

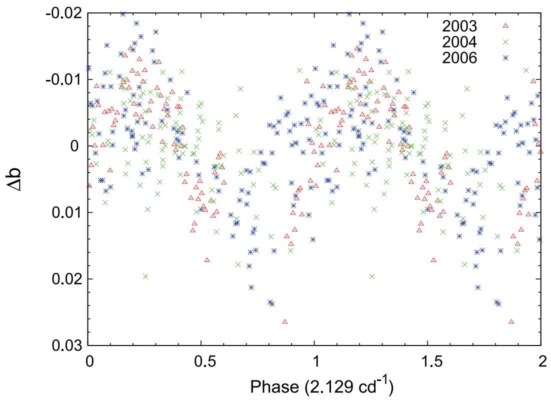

Fig. A.6. Phase diagram of the combined dataset obtained at the OSN for star HD 49330 folded with the frequency 2.129 c d^{-1}. Triangles in red, crosses in green and asterisks in blue correspond to the 2003, 2004 and 2006 observations, respectively.

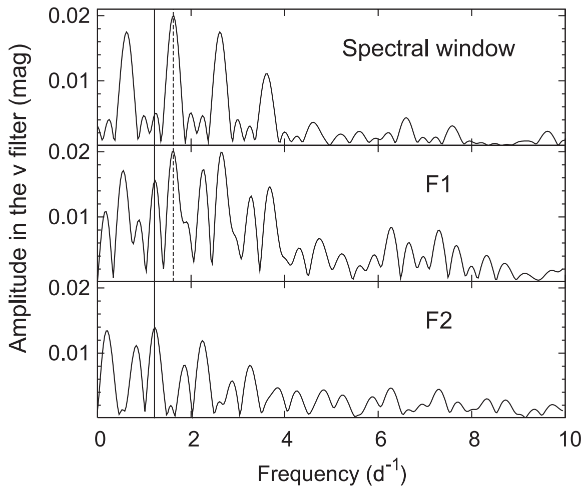

Fig. A.7. Successive periodograms and spectral window shifted at frequency $F1$ of the light curve of HD 49585 in the v filter. The dashed and solid vertical arrows stand for the position of frequencies $F1$ = 1.647 c d^{-1} and $F2$ = 1.218 c d^{-1}, respectively.

As a final check, we combined the data of the three seasons, which allowed us to detect a frequency at 2.129 c d^{-1}. This frequency is a 1-day alias of the frequency found in the 2006 data. In Fig. A.6 we show the light curve in phase with this frequency for the three seasons with different symbols and colours. This figure suggests that this frequency has been present in the light curve over the three years, but its amplitude has changed dramatically, from 13 mmag in 2003 to 4 mmag in 2004 and 8 mmag in 2006 in the v filter. Errors in the amplitude are of the order of 1 mmag in this filter.

The light curve of the ASAS-3 data shows a quasi-cyclical variation of about 1600 days, disturbed by an outburst of shorter duration of about 200 days. We noticed that the OSN data obtained in 2003 was observed during this short outburst.

A.1.8. HD 49585

There are no Hipparcos data for this faint star. This star was observed during one season at the OSN in 2004. Only detailed analysis for the v filter is provided here, since results with other filters are similar within errors. The periodogram shows strong peaks at frequency $F1$ = 1.647 c d^{-1} and its 1-day aliases (see middle panel of Fig. A.7). In the top panel of Fig. A.7, we represent the spectral window of the light curve shifted at frequency $F1$. Another peak is present in the data at frequency $F2$ = 1.218 c d^{-1}, which is not seen in the spectral window. Periodogram of the residuals after prewhitening for frequency $F1$ is depicted in the bottom panel of Fig. A.7. The 1-day alias of $F2$ (0.21 c d^{-1}) gives a similar fit, although the phase diagram for $F2$ is much better. The phase plots for frequencies $F1$ and $F2$ are displayed in Fig. A.8.

A long-term trend is apparent in the light curve of the ASAS-3 dataset, which does not allow us to search for short-term periodicity.

A.1.9. HD 50087

We observed this star in 2006 at the OSN. Different frequencies are detected in the four filters with very low SNR, suggesting that these frequencies are artifacts. The light curve of the ASAS-3 data does not show any significant variation.

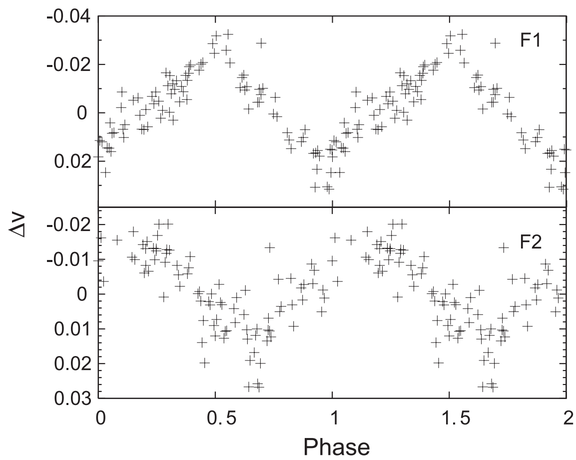

Fig. A.8. Phase plots of HD 49585 folded with the frequency $F1$ = 1.647 c d^{-1}, after prewhitening for $F2$ = 1.218 c d^{-1} (*top*) and with the frequency $F2$ = 1.218 c d^{-1} (*bottom*), after prewhitening for $F1$ = 1.647 c d^{-1}.

A.1.10. HD 50209

The Hipparcos data analysis yields to a frequency at 1.689 c d^{-1}, considered as uncertain. Another peak at frequency 1.47 c d^{-1} is also present, although with a lower amplitude.

This star was observed during three observing runs at the OSN. The 2003 dataset shows clear variability, but the time span of 9 h does not allow us to perform a spectral analysis. In 2004, a frequency at 1.52 c d^{-1} is clearly found in all filters, while in 2006 a similar frequency at 1.48 c d^{-1} is also detected in all filters. The combined data of the three seasons allows us to refine the frequency to 1.4889 c d^{-1} (see Fig. A.9). Note that we have removed the average magnitude of each year before combining the datasets.

The periodogram of the ASAS-3 dataset shows significant peaks at frequency 2.4803 c d^{-1} and its daily aliases. The phase plot with this frequency is depicted in Fig. A.10. This frequency is probably a 1-day alias of the frequency detected at the OSN. However, the phase diagram of the ASAS-3 dataset with the frequency 1.4889 c d^{-1} and the light curve obtained at the OSN folded with the frequency 2.4803 c d^{-1} are very

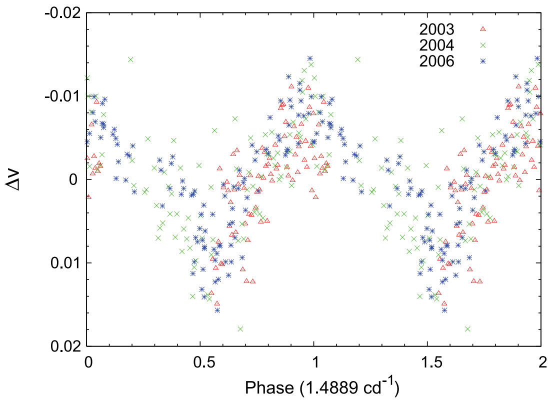

Fig. A.9. Phase plot of HD 50209 folded with the frequency 1.4889 c d^{-1} for the combined data obtained at the OSN. Triangles in red, crosses in green and asterisks in blue correspond to the 2003, 2004 and 2006 observations, respectively.

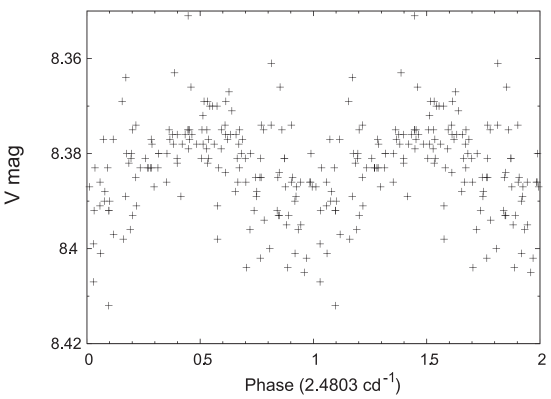

Fig. A.10. Phase plot of HD 50209 folded with the frequency 2.4803 c d^{-1} for the ASAS-3 dataset.

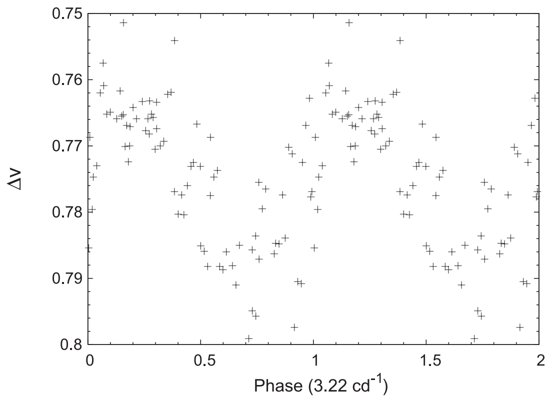

Fig. A.11. Phase plot of HD 50696 folded with the frequency 3.22 c d^{-1} for the OSN data obtained in 2004.

scattered. This could be due to the fact that the ASAS-3 dataset contains long- and mid-term trends or to the presence of multiple periods. After prewhitening for the frequency 2.4803 c d^{-1} in the ASAS-3 dataset, a frequency at 1.4749 c d^{-1} appears in the periodogram, but the phase diagram with this frequency is very scattered. More observational data is required to confirm the multiperiodicity of this star.

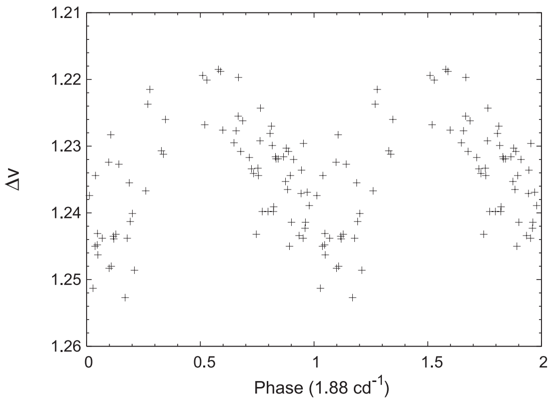

Fig. A.12. Phase plot of HD 50891 folded with the frequency 1.88 c d^{-1} for the OSN data obtained in 2004.

A.1.11. HD 50696

There are no Hipparcos data for this faint star. We observed this source during two seasons at the OSN. The 2003 dataset shows clear variability, but the time span does not allow us to perform any period analysis. A clear frequency at 3.22 c d^{-1} is detected in the 2004 photometry through the four filters. We present the phase diagram, only for the v filter data for clarity, in Fig. A.11. Note that the amplitude of the variation is of the order of 12 mmag. The phase diagram of the data obtained in 2003 is compatible with this frequency.

A long-term variation is found in the ASAS-3 dataset, which stops us from searching for short-term variability.

A.1.12. HD 50891

There are no Hipparcos data for this star. This star was only observed in 2004 at the OSN. The periodogram shows significant peaks at frequency 1.88 c d^{-1} and its 1-day aliases for all the filters. We present the phase curve with this frequency in Fig. A.12.

A long-term trend is apparent in the light curve of the ASAS-3 dataset, which does not allow us to search for short-term periodicity.

A.1.13. HD 51193

The Hipparcos light curve shows clear periodicity at frequency 1.639 c d^{-1}.

This star was observed at the OSN in 2004 and 2006. A long-term trend is present in the light curve of 2004, which we have removed with a low-order polynomial function. We found a frequency at 2.66 c d^{-1} in the *vby* filters, which is similar to a 1-day alias of the Hipparcos frequency. Both frequencies have a similar fit for the OSN data, although the phase diagram with the frequency 2.66 c d^{-1} is much better (see Fig. A.13). In 2006, the amplitude seems to vary from night to night, as shown in Fig. A.14. Unfortunately, we could not find any significant frequency with a coherent phase diagram.

The light curve obtained with the ASAS-3 project shows a long-term trend. After prewhitening for this trend with a low-order polynomial, a peak at frequency 1.6060 c d^{-1} and its daily aliases appear in the periodogram. The frequency fulfils the SNR criterion, but the phase diagram is very scattered. Note that this frequency is similar to the frequency detected in the Hipparcos data and the 1-day alias of the frequency detected at the OSN.

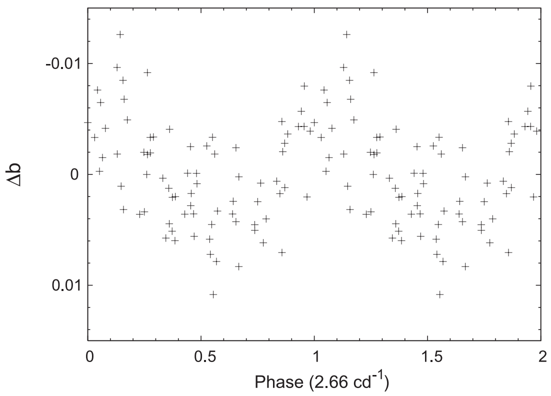

Fig. A.13. Phase plot of HD 51193 folded with the frequency 2.66 c d^{-1} in the *b* filter for the OSN data obtained in 2004.

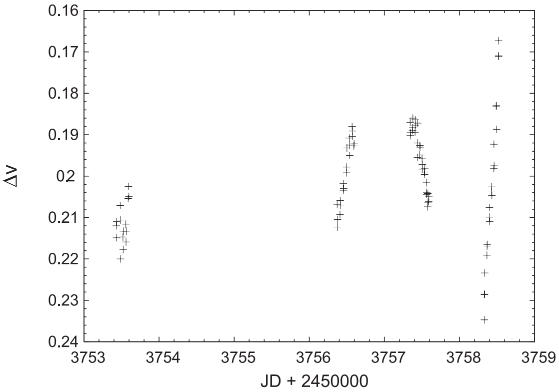

Fig. A.14. Light curve of HD 51193 for the OSN data obtained in 2006. Note the variation of the amplitude from night to night.

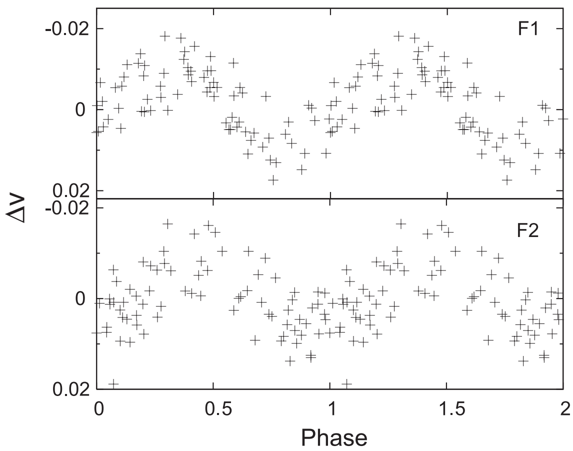

Fig. A.15. Phase plots of HD 51404 folded with the frequency $F1$ = 2.68 c d^{-1} after prewhitening for $F2$ = 5.99 c d^{-1} (*top*) and with the frequency $F2$ = 5.99 c d^{-1} after prewhitening for $F1$ = 2.68 c d^{-1} (*bottom*) in the *v* filter of the 2004 dataset.

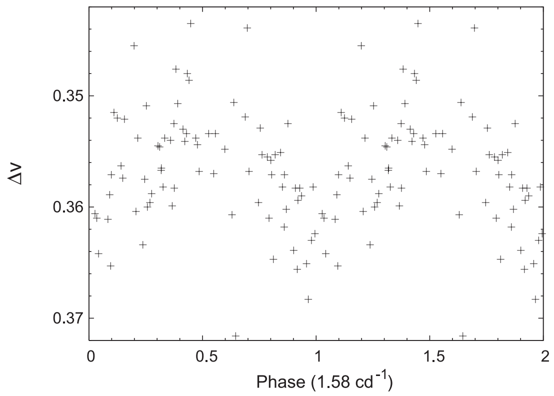

Fig. A.16. Phase plot of HD 51452 folded with the frequency 1.58 c d^{-1} in the *v* filter for the OSN data.

A.1.14. HD 51404

There are no Hipparcos data for this star. This star was only observed in 2004 at the OSN. It is clearly variable with an amplitude of 10 mmag. Strong peaks appear in the periodogram of the *vby* filters at frequency $F1$ = 2.68 c d^{-1} and its daily aliases. The light curve folded with this frequency is depicted in Fig. A.15 (upper panel). After prewhitening for this frequency, another significant frequency at $F2$ = 5.99 c d^{-1} is detected, also in the *vby* filters. The phase plot with this frequency is displayed in the lower panel of Fig. A.15, only for the *v* filter data for clarity.

The ASAS-3 light curve shows short- and long-term variability with a standard deviation of the observations of 24 mmag. However, no significant frequencies are found.

A.1.15. HD 51452

There are no Hipparcos data for this star. We observed this star at the OSN in 2004. The light curve shows variability with the frequency 1.58 c d^{-1}, but only in the *vy* filters, and thus, this frequency is considered as uncertain. The phase diagram with this frequency is displayed in Fig. A.16 for filter *v*. The ASAS-3 data does not show any indication of variability.

A.2. Stars in the Galactic centre direction

A.2.1. HD 170 714

The few datapoints collected by the Hipparcos mission for this star do not allow us to search for short-term variability.

This star was observed at the OSN in 2005. Strong peaks at frequency 3.79 c d^{-1} and its 1-day aliases appear in the periodogram of all the filters. The amplitude corresponding to this frequency is 10 mmag for the *vby* filters (±1 mmag) and 13 for the *u* filter (±2 mmag). In Fig. A.17 we represent the light curve folded in phase with the detected frequency for the *b* filter.

This star is saturated in the ASAS-3 dataset.

A.2.2. HD 171 219

This star is classified as constant in the Hipparcos catalogue. We have re-analysed the light curve and no short-term variability has been found. We observed this star at the OSN during two seasons, in 2002 and 2003. The periodograms of both datasets do not show any significant peak greater than 2 mmag. We conclude that the star is not variable at our detection level. This star is saturated in the ASAS-3 database.

A.2.3. HD 173 292

The Hipparcos data show short-term variability with a standard deviation of 30 mmag. However, no significant frequencies were detected in the Fourier analysis.

The spectral analysis of the ASAS-3 dataset shows peaks at frequency 0.6824 c d^{-1} and its daily aliases. A phase diagram

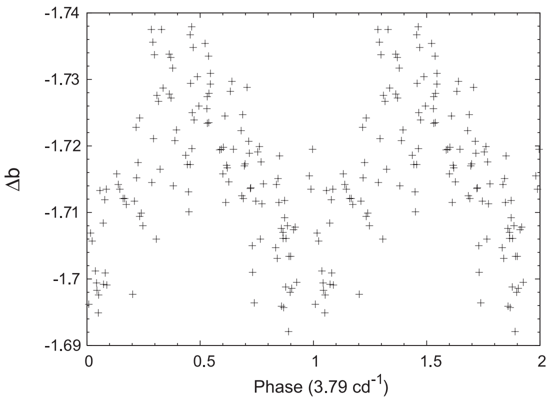

Fig. A.17. Phase plot of HD 170 714 folded with the frequency 3.79 c d^{-1} in the *b* filter for the OSN data.

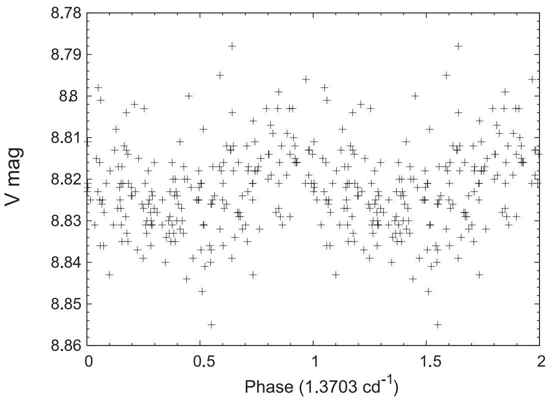

Fig. A.19. Phase plot of HD 173 530 with the frequency 1.3703 c d^{-1} for the ASAS-3 dataset.

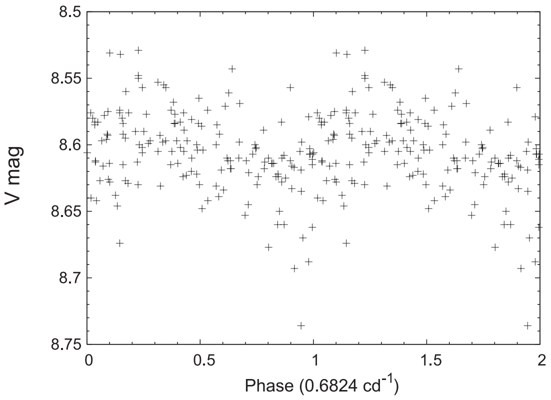

Fig. A.18. Phase plot of HD 173 292 folded with the frequency 0.6824 c d^{-1} for the ASAS-3 dataset.

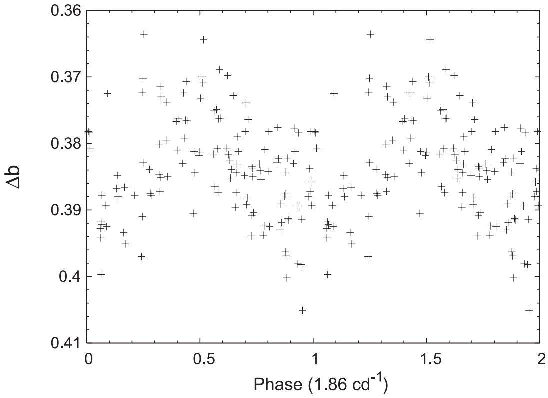

Fig. A.20. Phase plot of HD 173 637 folded with the frequency 1.86 c d^{-1} in the *b* filter for the OSN data.

with this frequency is depicted in Fig. A.18. Note the high amplitude of the variation (~16 mmag).

This star was not observed at the OSN.

A.2.4. HD 173 530

There are no Hipparcos data for this faint star. A significant peak at frequency 1.3703 c d^{-1} appears in the periodogram of the ASAS-3 light curve with an amplitude of 6 mmag. A phase diagram for this frequency is plotted in Fig. A.19.

This star was not observed at the OSN.

A.2.5. HD 173 637

The Hipparcos data show a long-term variation, which does not allow us to search for short-term periodicity.

This star was observed at the OSN during two seasons, in 2003 and 2005. However, only 19 datapoints were obtained in 2005 and therefore no result can be achieved with this dataset. Short-term variability is found in the 2003 dataset. We detect significant peaks in the frequency domain at 1.86 c d^{-1} and its 1-day aliases. The amplitude of this frequency is of the order of 5 mmag in the *vby* filters and the SNR is 4.8. The phase diagram with this frequency in the *b* filter is displayed in Fig. A.20.

A long-term trend is present in the ASAS-3 light curve (Fig. A.21), superimposed on which we see several outburst (at least 3) with an amplitude of 0.1 mag and a time difference of around 360 to 380 days. We have not searched for short-term periodicity because of the complexity of the light curve.

A.2.6. HD 173 817

The Hipparcos light curve does not show any indication of variability.

This star was observed at the OSN in 2003. The light curve shows short-term variability with the frequency 3.51 c d^{-1} in the *vby* filters, which fulfils the SNR criterion. However, the amplitude is of the order of 3 mmag and thus, the phase curve is very scattered.

A long-term trend is present in the ASAS-3 light curve. We do not find short-term variability after removing the long-term variation. The frequency found at the OSN is not detected in the ASAS-3 dataset, probably due to the fact that the ASAS-3 photometry have lower precision. More observational data are required to confirm the periodicity of this star.

A.2.7. HD 174 513

Long- and short-term variations are found in the Hipparcos light curve. However, the frequency analysis does not yield any frequency with a coherent phase diagram.

The analysis of the dataset obtained at the OSN in 2002 confirms its variability with frequencies at 3.34 c d^{-1} and its 1-day aliases. However, this frequency is very uncertain due to the low amplitude (4 mmag) and the few observed datapoints.

In the ASAS-3 dataset, a long-term trend is present, was removed with a low-order polynomial. The periodogram of the residual shows a strong peak at the low-frequency $F1$ = 0.0271 c d^{-1} (i.e. 36.90 d) and its daily aliases. A phase plot for this frequency is displayed in the upper panel of Fig. A.22.

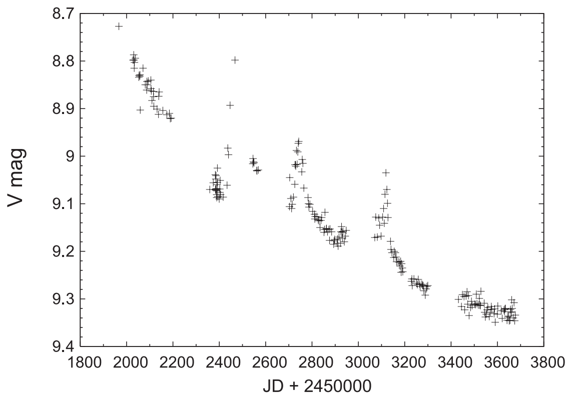

Fig. A.21. Light curve of HD 173 637 for the ASAS-3 dataset.

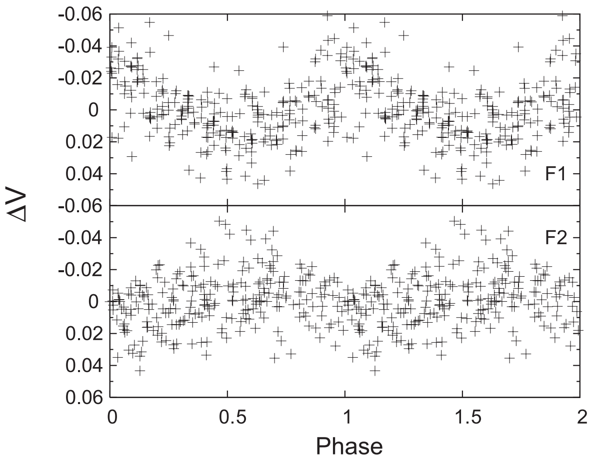

Fig. A.22. Phase plot of HD 174 513 folded with the frequency $F1 = 0.0271$ c d^{-1}, after prewhitening for $F2 = 5.293$ c d^{-1} (*top*) and with the frequency $F2 = 5.293$ c d^{-1}, after prewhitening for $F1 = 0.0271$ c d^{-1} (*bottom*) for the ASAS-3 dataset.

This frequency is too low to be produced by pulsations and it is probably caused by a binary component. Prewhitening for this frequency, we found an additional significant frequency at $F2 = 5.293$ c d^{-1} with an amplitude of 8 mmag, which is similar to a 1-day alias of frequency found at the OSN (3.34 c d^{-1}). A phase diagram of this frequency is plotted in the lower panel of Fig. A.22. More photometric data are required to confirm the frequency $F2$.

A.2.8. HD 174705

There is neither Hipparcos nor OSN data for this star. The ASAS-3 light curve contains individual subsets with different mean magnitudes due to the fact that the star was observed in several different fields, as pointed out by Pojmanski (2002). Therefore, the mean magnitude has first been subtracted from each subset and then the subsets were combined. A significant peak appears at frequency 2.3164 c d^{-1} in the periodogram of the combined dataset. The light curve folded in phase with this frequency is displayed in Fig. A.23.

A.2.9. HD 181231

The Hipparcos data do not show any indication of variability. We observed this star at the OSN in 2003. Unfortunately, the comparison star HD 182 786 showed variability during the observing

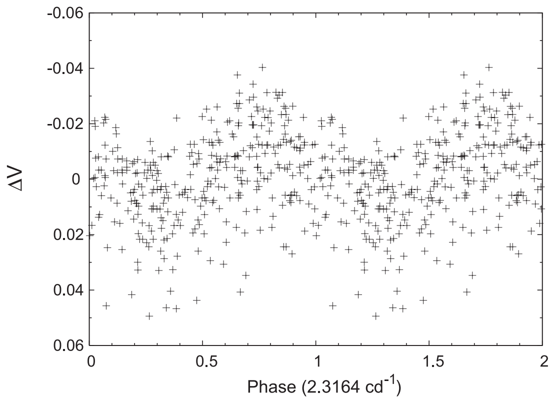

Fig. A.23. Phase plot of HD 174 705 folded with the frequency 2.3164 c d^{-1} for the ASAS-3 dataset.

run, and thus no reliable result can be obtained with this comparison star. Using the check star HD 182 198, a significant peak appears in the periodogram of all filters at frequency 0.67 c d^{-1}, but the phase coverage is not complete. In addition, we analysed photometric data obtained by Ennio Poretti at San Pedro Martir (SPM). HD 181414 was used in the differential photometry as the comparison star. Frequency 0.67 c d^{-1} is also detected in the *vby* filters. The amplitude associated to this frequency is 4 and 3 mmag at the OSN and SPM, respectively.

We also performed a detailed analysis of the ASAS-3 light curve, which shows short-term variability with the frequency 3.4304 c d^{-1}. However, this frequency is considered as uncertain due to the low value of the associated amplitude (5 mmag). The ASAS-3 dataset was also plotted in phase with the frequency 0.67 c d^{-1}, resulting in a scattered diagram. The periodogram of the combined data (OSN, SPM, ASAS-3) yields a frequency of 0.6425 c d^{-1}. However, the phase diagram has a large scatter and therefore we cannot confirm this frequency.

A.2.10. HD 181 367

There are no Hipparcos data for this star. No short-term variability is found in the light curve obtained at the OSN in 2003 with an amplitude exceeding 4 mmag. The same conclusions have been reached by Ennio Poretti (priv. comm.) in the analysis of the SPM data for this star.

The ASAS-3 light curve shows a long-term trend. After removing it with a low-order polynomial, we do not find any indication of variability.

A.2.11. HD 183 656

HD 183 656 is a spectroscopic binary shell star (SB1) with an orbital period of 214.75 d (Koubsky et al. 1989). This star was found to be variable by Lynds (1960), who proposed a period of 0.8518 d (i.e. 1.1740 c d^{-1}). Short-term variability with a period of 0.652 d (i.e. 1.534 c d^{-1}) was obtained from the Hipparcos photometry (Hubert & Floquet 1998).

We observed this star at the OSN in 2002 and 2005. In the periodogram of the 2002 light curve, the most powerful peak appears at frequency 2.19 c d^{-1}, although the phase diagram is very scattered. Note that the 1-day alias of this frequency is Lynds' period. However, the Hipparcos data appear very noisy when folded with any of the two frequencies. The 10-day light curve obtained in 2005 shows a long-term trend, which were removed with a low-order polynomial function. After prewhitening for

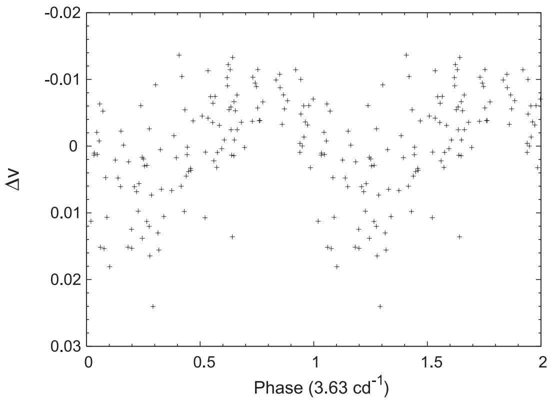

Fig. A.24. Residuals of HD 183 656 in phase with the frequency 3.63 c d^{-1}, after removing the long-term trend.

this trend, a significant peak appears at frequency 3.63 c d^{-1} in the periodogram of the light curve in the *vby* filters with an amplitude of 7 mmag (Fig. A.24). The 2.19 c d^{-1} frequency is not detected in the 2005 data. This star is saturated in the ASAS-3 database.

A.2.12. HD 184 279

Percy et al. (2002) performed an autocorrelation analysis of the Hipparcos data for this star and found a period of 0.6 days (i.e. 1.667 c d^{-1}), which they presented as uncertain. A re-analysis of the Hipparcos data with the methods explained above yields a period of 0.156 d (i.e. 6.410 c d^{-1}), although the phase diagram is very scattered.

We observed this star at the OSN in 2002 and 2005. The periodogram of the 2002 dataset shows a peak at frequency 1.38 c d^{-1}, but we cannot confirm this frequency due to the few points of the sample. The 3-night light curve obtained in 2005 confirms the presence of short-term variability for this star. However, frequencies found in the spectral analysis have very scattered phase diagrams and thus are also very uncertain. The long-term trend that is present in the ASAS-3 dataset does not allow us to search for short-period variability. We conclude that this star is variable, but more observations are needed to confirm its periodicity.