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Selection of a sample of bright southern Slowly Pulsating B Stars for long-term photometric and spectroscopic monitoring*

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Abstract. The photometric experiment on Hipparcos has led to the discovery of, among other types of variables, a large amount of new Slowly Pulsating B Stars. We have selected twelve bright southern stars of this sample, together with five previously known Slowly Pulsating B Stars, for spectroscopic and photometric monitoring. These seventeen stars have spectral types ranging from B 2 up to B 9 and thus fully cover the instability strip. We here present the results of a preliminary analysis of our data and show that our sample is an extremely important one to perform seismology of intermediate-massive stars.

In particular, we find that all but one of the selected stars exhibit clear line-profile variability. The broader-lined Slowly Pulsating B Stars tend to have more complex line-profile variations. One of the previously known Slowly Pulsating B stars was known to be a binary. Besides this star, another six of the selected Slowly Pulsating B stars turn out to be multiple systems. Five of these seven binaries have large rotational velocities and complicated line-profile variations with moving subfeatures. It is not yet clear whether or not the binarity results in a particular spectrum of excited modes.

Key words: stars: variables: general – stars: binaries: spectroscopic – stars: oscillations – stars: early-type

1. Introduction

Of the 267 new B-type variables discovered by Hipparcos, some 100 turn out to be Slowly Pulsating B Stars (hereafter called SPBs). Waelkens et al. (1998) have classified all these new variables and determined the position of the SPBs in the HR diagram. They find that the new SPBs fully cover the instability strip calculated by Pamyatnykh (1999).

SPBs are the most interesting massive stars for seismological purposes, since they pulsate in many high-order g-modes which penetrate deep into the stellar interior and for which asymptotic pulsation theory applies. In this respect, they can be viewed as intermediate-mass main-sequence analogues of the white dwarfs, for which seismological studies have been very successful in the recent past (see e.g. Winget et al. 1991). For a recent review on theoretical aspects in asteroseismology we refer to Christensen-Dalsgaard (1998), while Dziembowski (1998) outlined the seismological prospects of B stars in particular and pointed to the problems that still occur before successful application. Besides this, all the newly discovered members of the group deserve to be studied because we have for the first time a large sample of SPBs with no bias regarding spectral type and periodicity.

From an observational point of view, a large disadvantage of SPBs is that long-term monitoring is necessary in order to obtain meaningful results. The beat-periods in these stars are of the order of months/years and have to be covered to disentangle the complete frequency spectrum and to perform mode identifcations. An advantage, however, is that many of the newly discovered SPBs are sufficiently bright to study their variations by means of line-profile studies. Moreover, accurate photometry can be performed with small telescopes.

In this paper, we present a sample of SPBs that we have selected for long-term photometric and spectroscopic monitoring. The goal of our long-term project is to improve our knowledge of the pulsational character of the SPBs. The observational characteristics of SPBs are still far from complete since simultaneous photometry and spectroscopy has never been performed on any of them. Our approach will allow us to make an inventary of the observed character of the pulsations in a large sample of SPBs. These observational results can then be used to improve the theoretical pulsation codes which led to the construction of the theoretical SPB instability strip. Once excellent agreement between theory and observations is established, the theoretical models can be used to perform seismology of the SPBs with the aim to derive the internal structure of intermediate B-type stars with high accuracy.

This paper is organised as follows. The selected SPBs are described in Sect. 2, as well as the kind of data that we have

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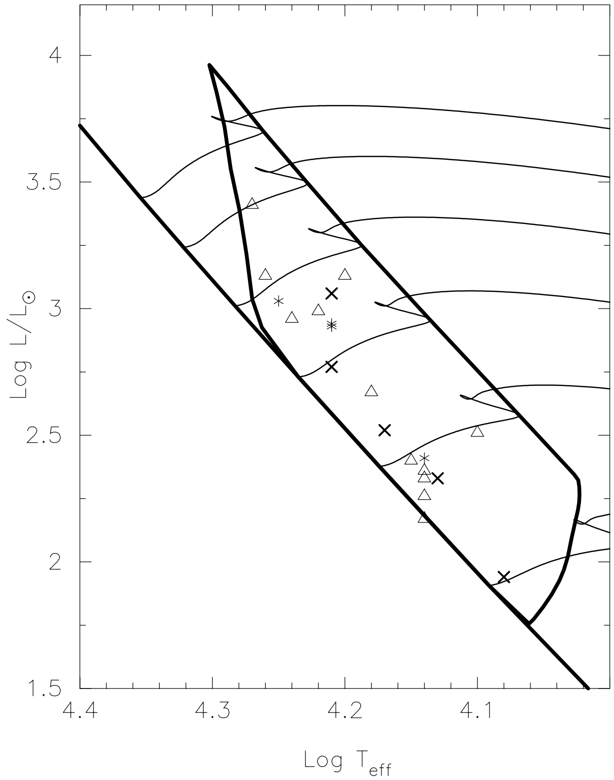

Fig. 1. Position of the considered bright southern SPBs in the HR diagram (crosses: selected SPBs discovered by Waelkens (1991), triangles: selected Hipparcos SPBs, asterisks: Hipparcos SPBs that have a too large line broadening for spectroscopic monitoring). The stellar parameters of the stars are listed in Table 1. The theoretical SPB instability strip is calculated by Pamyatnykh (1999) and is based on OPAL G93/21 opacities (Iglesias & Rogers 1996) for a composition $X, Z = 0.70, 0.02$. No overshooting was considered. The evolutionary tracks for 3, 4, 5, 6, 7, 8 $M_\odot$, as well as the instability strip, were kindly made available to us by Dr. Pamyatnykh

obtained for a detailed analysis. In Sect. 3, we present preliminary results for all the targets based on Hipparcos data and on our ground-based photometric and spectroscopic data that were gathered during the first year of our observational programme. A discussion of our preliminary results is given in Sect. 4. Finally, our future plans for the study of these stars is given in Sect. 5.

2. Selection of the programme stars

Of the many SPBs discovered from the Hipparcos mission, we have selected the brightest southern stars from the list given by Waelkens et al. (1998) as candidates for further follow-up monitoring. Besides these stars we also considered five SPBs that were discovered by Waelkens (1991) from his systematic study of variable B stars. The stars that were considered for our selection test, and some of their physical parameters, are listed in Table 1. Their position in the HR diagram with respect to the theoretical SPB instability strip is shown in Fig. 1. The effective temperature, gravity, luminosity, and mass were estimated by means of the Geneva data in the same way as outlined in Waelkens et al. (1998), only this time we added all the recent follow-up Geneva data. Our estimates of these parameters should therefore be preferred above those listed by Waelkens et al. (1998).

The spectral types of the targets range from B 2 up to B 9. This results in an important limitation concerning the choice of a suitable spectral line to be used for the high-resolution spectroscopic monitoring. In order to plan the monitoring in an efficient way, we need to consider a spectral line with a profile that is sufficiently deep and unblended for the whole range of spectral types. The Si II doublet centered at $\lambda\lambda\, 4128, 4130$ Å best fulfills these conditions and was therefore chosen for the spectroscopic runs. The high-resolution spectra are taken with the CAT telescope of the European Southern Observatory in Chile.

We first started of by taking one Si II spectrum for each of the candidate targets. For four stars, the Si II doublet is blended due to large broadening, which is presumably due to a large rotational velocity and/or a companion. Consequently, we observed the Si III triplet centered around $\lambda\lambda\, 4560$ Å to see if these lines could be a good alternative to the Si II doublet. This turned out not to be the case. For HD 55718 and HD 64503 we find that $v \sin\, i$ must be larger than 200 km/s, unless the pulsational broadening in these stars would be extremely large. For HD 79416 and HD 109026 we were not able to determine the continuum level and we cannot give an estimate of the rotational/pulsational velocity. Both stars, however, are rapid rotators according to the BSC (see Table 1).

The other seventeen stars did have suitable Si II lines for spectroscopic monitoring. We present one typical spectrum for each of these stars in Fig. 2. It can be noticed from this figure that both broad and sharp lines appear in the target stars. We derived the total broadening of the lines and list them as an upper limit for the rotational velocity in Table 1 since at present it is not clear which fraction of the broadening is due to pulsation. Although we can give only upper/lower limits for $v \sin\, i$, it is clear that SPB-type pulsations are not limited to slow rotators as was up to now thought to be the case (see e.g. Waelkens 1991). On the other hand, most of the SPBs that we considered have rotation velocities significantly lower than the ones found for the λ Eri stars (Balona 1995).

Although the most rapid rotators among the sample form a very interesting group of pulsators from a theoretical point of view (see e.g. Ushomirsky & Bildsten 1998), they were no longer considered to be good candidates for our current long-term monitoring project. The reason is that they are a minority among the candidate stars for monitoring and we would have to switch to other wavelengths to obtain useful profile variations. This would imply too much loss of observing time. A special observing project should be devoted to these most rapid rotators among the SPBs. The loss of the most rapidly rotating SPBs by our selection prevents us from deriving general properties of the pulsational behaviour of the SPBs as a function of the complete rotational velocity range that occurs in these stars. On the other hand, the group of stars that were monitored in the wavelength range of Si II still has a broad range in rotational velocities (see

Table 1. Stellar parameters of the southern SPBs that were considered for long-term photometric and spectroscopic monitoring. The confirmed SPBs are some of those discovered by Waelkens (1991) by means of ground-based photometry, the candidate SPBs are the ones selected from the Hipparcos data, the rapid rotators are Hipparcos SPBs that turn out to have a too rapid rotation to be monitored spectroscopically. $\triangle T$ stands for the integration times in the case of optimal atmospheric conditions. The total broadening of the line profiles is given in the second last column and is considered as a limit for vsini.

Star	m_V	$\triangle T(min)$	SpT (BSC)	log $T_{\rm eff}$	log g	log $L/L_\odot$	M ($M_\odot$)	vsini (km/s)	freq.(c/d)
				selected confirmed SPBs					
HD 74195	3.6	4	B3IV	4.21	3.90	3.06	5.4	< 40	0.3575 [1]
HD 74560	4.9	10	B3IV	4.21	4.15	2.77	4.9	< 45	0.6447 [1]
HD 123515	6.0	25	B9IV	4.08	4.25	1.94	3.0	< 15	0.6852 [1]
HD 177863	6.3	30	B8III	4.13	4.14	2.33	3.7	< 75	0.8407 [1]
HD 181558	6.3	30	B5V	4.17	4.16	2.52	4.2	< 20	0.8078 [1]
				selected Hipparcos SPBs					
HD 24587	4.7	10	B6V	4.14	4.21	2.33	3.8	< 40	1.1570 [2]
HD 26326	5.4	15	B4V	4.18	4.10	2.67	4.5	< 30	0.5339 [2]
HD 53921	5.5	20	B9IV	4.14	4.24	2.26	3.7	< 65	0.6054 [2]
HD 55522	5.9	25	B2IV/V	4.24	4.15	2.96	5.5	< 85	0.3664 [2]
HD 69144	5.1	15	B2.5IV	4.20	3.81	3.13	5.6	< 70	0.4146 [3]
HD 85953	5.9	20	B2III	4.27	3.89	3.41	6.7	< 45	0.2662 [2]
HD 92287	5.8	20	B3IV	4.22	3.99	2.99	5.3	< 80	0.2148 [2]
HD 131120	5.0	15	B7II/III	4.26	4.10	3.13	6.1	< 65	0.6374 [2]
HD 138764	5.2	15	B6IV	4.15	4.18	2.40	3.9	< 30	0.7945 [2]
HD 140873	5.4	15	B8III	4.14	4.36	2.17	3.6	< 80	1.1515 [2]
HD 169978	4.6	10	B7–8III	4.10	3.89	2.51	3.8	< 90	1.1686 [3]
HD 215573	5.4	15	B6IV	4.14	4.18	2.36	3.8	< 15	? [4]
				rapidly rotating Hipparcos SPBs					
HD 55718	5.9	25	B3V	4.21	4.01	2.94	5.2	> 200	1.4267 [5]
HD 64503	4.4	8	B2.5V	4.25	4.12	3.03	5.7	> 200	1.7985 [5]
HD 79416	5.5	20	B8V	4.14	4.15	2.41	3.9	? (BSC: 384)	0.3437 [5]
HD 109026	3.8	5	B5V	4.21	4.00	2.93	5.1	? (BSC: 188)	0.3664 [5]

[1] main frequency found by Waelkens (1991); [2] frequency found from the Hipparcos and the Geneva photometry; [3] the main frequency is connected with orbital motion; [4] a different frequency is found in the Hipparcos, Geneva, and radial-velocity data; [5] frequency found from the Hipparcos photometry

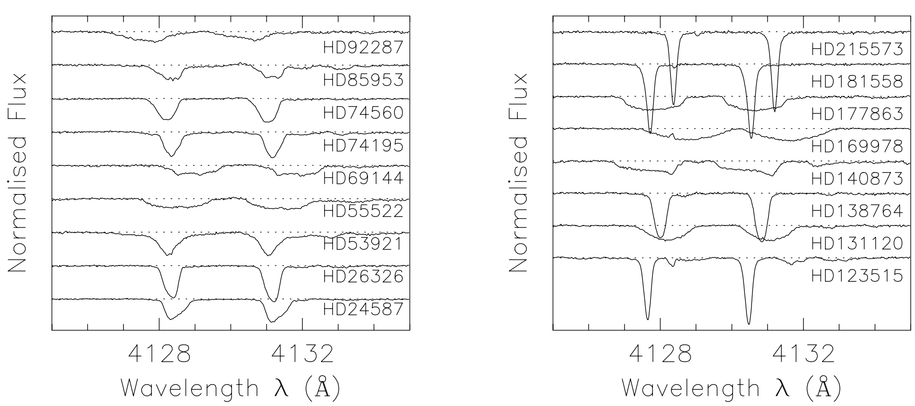

Fig. 2. One arbitrarily chosen spectrum of the Si II doublets centered around 4130Å for each of the 17 SPBs that were selected for extensive photometric and spectroscopic monitoring

Table 1), ranging from 0 up to 90 km/s. This range should allow us to find out if there is some correlation between the occurence of certain pulsation modes and rotation.

We finally have selected twelve bright southern Hipparcos SPBs, together with five bright ones previously found by Waelkens (1991), for long-term photometric and spectroscopic monitoring (see Table 1). The targets in this smaller sample are still well spread across the instability domain (see Fig. 1). Our sample thus allows us to obtain a general overview of the pulsations in the complete temperature range of SPBs.

As already mentioned, we started our spectroscopic monitoring in 1996 and we were allotted telescope time with the CAT up to March 1998. The ground-based photometric data of the seventeen targets are gathered with the Swiss Telescope of the Geneva Observatory situated at La Silla in Chile. The dedicated photometric monitoring was almost entirely performed in the course of 1997 but for many of the targets earlier data are available as well. The number of data points available until July 1997 for the twelve Hipparcos SPBs ranges from 46 up to 228. For a description of the Geneva data of the five SPBs discovered by Waelkens (1991), we refer to his paper.

We here present the basic results for the variability derived from the Hipparcos data and from respectively six months and one year of devoted ground-based photometric and spectroscopic follow-up monitoring. More specifically, we consider spectroscopic data obtained between March 1996 an February 1997 while all Geneva photometric observations obtained until July 1997 are considered. A more thorough analysis will be performed once all the planned data have been accumulated and reduced. This will be the subject of subsequent papers.

3. Results for the individual targets

In this section, we describe the results of our very basic analysis of the different kinds of observations for each of the targets. In doing so, we first of all consider the Hipparcos photometry from which the stars were classified as candidate SPBs. The main period found from the Hipparcos data was already listed by Waelkens et al. (1998). A detailed frequency analysis of the Hipparcos photometric data of the new SPBs with the specific aim to search for multiperiodicity will be presented elsewhere (Cuypers et al., in prep.) and is omitted here. Instead, we show the phase diagrams based on the Hipparcos photometry for the selected stars and confront them with those obtained from the ground-based Geneva photometry. For the latter, we searched for the main frequency in the Geneva V filter.

We next compare the phase diagrams based on the photometry with the radial-velocity data. The latter are derived from the observed line-profile variations, which we obtained in March, April, and July 1996, and in February 1997. The radial velocity was calculated by means of the first moment of the line profiles (for a definition, see e.g. Aerts et al. 1992) and thus represent the true mean disc velocity weighted with limb darkening. The reason to prefer the first moment above e.g. the centre of a Gaussian fit to the lines is that the latter is a bad approximation of the radial velocity in the case of asymmetric profiles. We used the average values of the first moment of the two Si II lines. For most stars, the time spread of the spectroscopic data is still insufficient to determine the periods in an accurate way. We therefore postpone a detailed frequency analysis based on the line-profile variations until all the planned data are available.

The results for the individual stars are given in the following subsequent sections. A summary of the results can be found in Figs. 3–14. All the phases used in these figures were calculated with respect to the reference epoch $T_0 =$ HJD 2 400 000.

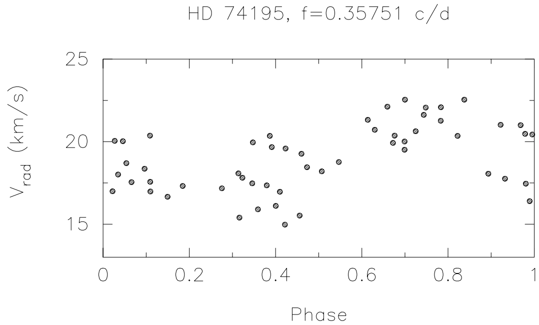

Fig. 3. The radial-velocity data of HD 74195 folded with the main frequency found from photometric data

3.1. Confirmed SPBs

We first describe the results for the five previously known SPBs that we took from the paper by Waelkens (1991). We here omit the photometry for these objects since Waelkens (1991) already devoted a lot of attention to their photometric behaviour.

3.1.1. HD 74195

This star (*o* Vel) pulsates in at least five modes, of which the main one has a frequency of 0.35751 c/d. *o* Vel was already reported to be a line-profile variable by Waelkens (1987) more than 10 years ago, but a systematic spectroscopic study was not performed so far. We gathered 54 spectra for *o* Vel during the first four runs. The radial velocities derived from our data are folded with the main photometric frequency in Fig. 3. It can be seen from this figure that the same frequency dominates both the photometric and the spectroscopic behaviour. This is confirmed by a period search on the radial-velocity data. We find a peak-to-peak variation of some 7 km/s. In view of the fact that the star undergoes at least five modes and that the total broadening of the lines is limited to 40 km/s we must be dealing with a slow rotator.

3.1.2. HD 74560

HY Vel is the other known SPB for which Waelkens (1987) already has reported line-profile variations. The star has at least three pulsation modes of which the dominant one has a frequency of 0.64472 c/d (Waelkens 1991).

Our radial-velocity data clearly point out the presence of a longer period, as can be seen on the top panel of Fig. 4. We find that the data are best represented by a sine fit with a period of some 8.8 days and a rather large amplitude of 8 km/s. Since such a variation is not clearly found in the extensive set of photometric data it cannot be due to a large-amplitude low-degree pulsation. Moreover, the period is longer than the ones predicted for SPBs by theoretical models (Moskalik, 1995). We therefore suggest that this star is a single-lined spectroscopic binary. With the data presented here, we are not able to derive an accurate orbital solution. As shown below, more target SPBs turn out to be binaries and a special paper will be devoted to the deduction

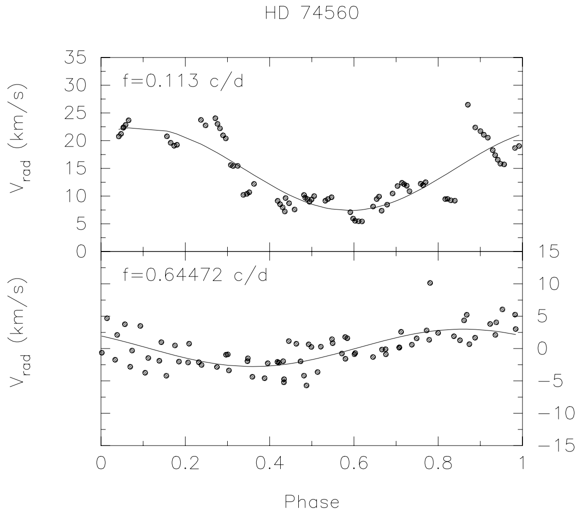

Fig. 4. Phase diagrams of the radial-velocity data of HD 74560. The top panel is constructed with the main frequency found in the data, while the lower panel shows the phase diagram for the main photometric frequency after prewhitening with 0.113 c/d

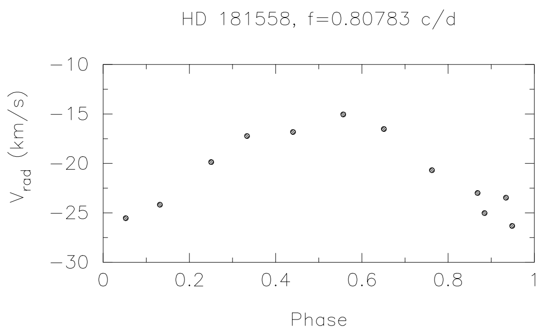

Fig. 5. The radial-velocity data of HD 181558 folded with the main frequency found from photometric data

of the orbital parameters based on the complete spectroscopic data sets (De Cat et al., in prep.).

After prewhitening with this new period, the data seem to be consistent with the main period found in the photometry (Fig. 4, lower panel). We find a pulsational peak-to-peak variation and a total line broadening comparable to the ones found for *o* Vel.

3.1.3. HD 123515

This SPB was known as a single-lined spectroscopic binary with a period of 26 days (Evans et al. 1967), but our data give evidence for the presence of the companion in the high-resolution spectra. We refer to De Cat et al. (in prep.) for a complete description of the highly excentric orbit. There is no evidence of the binarity in the Geneva and Hipparcos photometry and the latter data sets point towards the same main pulsation mode with frequency 0.68521 c/d. Together with HD 215573, HD 123515 has the sharpest lines among our sample with a total broadening that is limited to some 15 km/s. It is also the coolest among the SPB sample. A time series of the profiles that were gathered during 1996 is shown in Aerts et al. (1998).

3.1.4. HD 177863

The star HD 177863 turns out to be a single-lined spectroscopic binary. The radial-velocity data result in a standard deviation of 26 km/s, far too large to be due to pulsation. We again refer to De Cat et al. (in prep.) for a description of the orbital motion. Besides the clear evidence for orbital motion in our data, we find that the star has broad Si II lines (see Fig. 2) that show a lot of asymmetries due to intrinsic variability.

One main period emerges from both the Geneva and the Hipparcos photometry. A second small-amplitude variation was also clearly found in the Geneva data by Waelkens (1991). We were not able to find this second frequency in the Hipparcos photometry.

3.1.5. HD 181558

Waelkens (1991) has found three modes in this star, of which the main one has a significantly larger amplitude than the two others. This main frequency of 0.80783 c/d is easily recovered from the Hipparcos data, but the other two small-amplitude modes are not detected by Hipparcos.

Our spectroscopic data show that the star has sharp lines with a total broadening that is limited to some 20 km/s. Although we only gathered 12 spectra spread over 5 days until February 1997, we clearly find that the main variation in the radial velocity corresponds to the frequency found from the photometry. A phase plot of the radial-velocity data folded with 0.80783 c/d is shown in Fig. 5. We find a peak-to-peak variation of some 10 km/s.

3.2. Hipparcos SPBs

We next turn our attention to the candidate SPBs that were identified as such by means of the Hipparcos photometry.

3.2.1. HD 24587

We considered only 12 spectra of this star so far, so we were unable to determine a frequency from the radial velocities. The Hipparcos and Geneva photometry both lead to a main frequency of 1.1570 c/d. This star has one of the shortest periods in our sample. A plot of the phase diagrams of all the data for this frequency is shown in Fig. 6. It is not yet clear if the main photometric frequency is also dominant in the spectra. Remarkable is the large peak-to-peak variation in the radial velocity: some 20 km/s. We also note that the radial velocity data were obtained during two separate runs and that the three largest radial velocities were recorded during a different run than the other velocities. We therefore tentatively suggest that this star is a spectroscopic binary.

3.2.2. HD 26326

The Hipparcos and Geneva photometry lead to the same main frequency of 0.5339 c/d for HD 26326. As for the previous star,

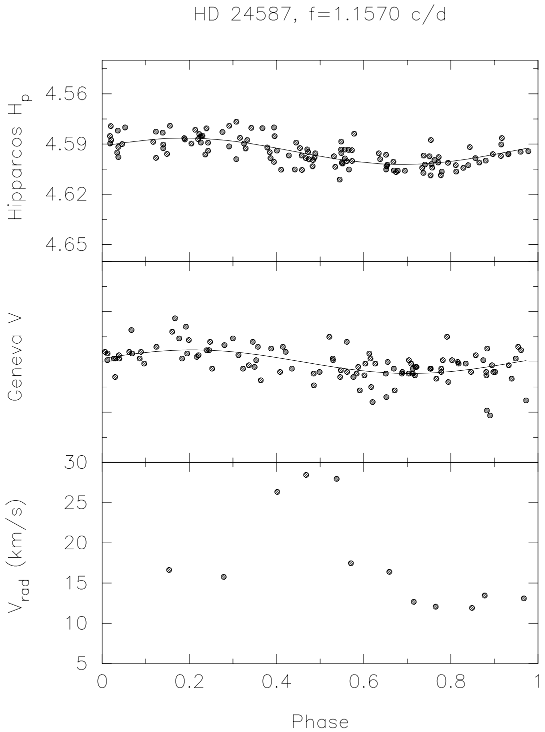

Fig. 6. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 24587 for the frequency 1.1570 c/d

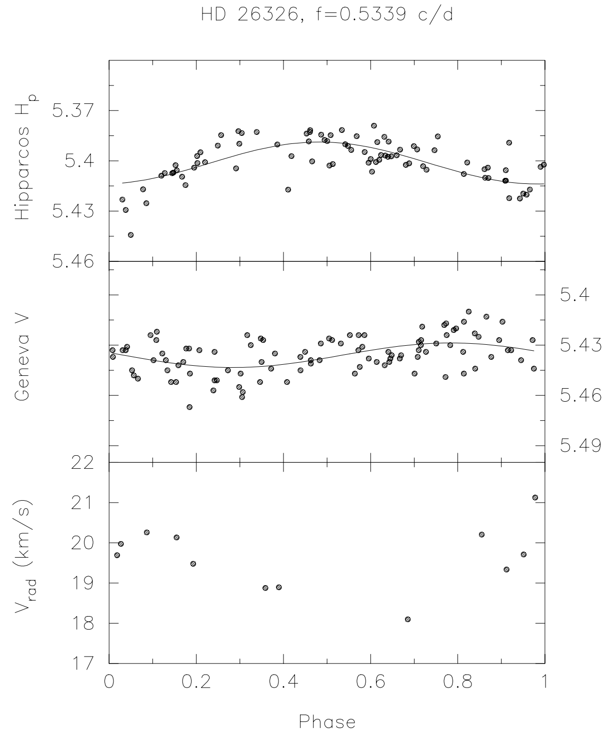

Fig. 7. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 26326 for the frequency 0.5339 c/d

we obtained only 12 spectra so far. Phase plots are shown in Fig. 7. The main variability in the radial velocity seems to be dominated by another frequency, but this should be checked by more follow-up spectra. The peak-to-peak variation is limited to 3 km/s.

3.2.3. HD 53921

For HD 53921, we find one common main frequency in the Hipparcos, Geneva, and radial-velocity data. Phase diagrams for this frequency are given in Fig. 8. The phase plots show that both the Geneva photometry and the spectra indicate the presence of other frequencies. Although the line profiles have rather complex variations with small moving subfeatures, we find a rather large peak-to-peak variation of some 10 km/s. The star is situated on the blue edge of the instability domain (see Fig. 1).

3.2.4. HD 55522

The Hipparcos and Geneva data of HD 55522 lead to the same main frequency of 0.3664 c/d. The amplitude of the photometric variability is fairly large. Surprisingly, the line profiles do not give evidence of this frequency, as can be seen on Fig. 9. The radial-velocity variation is complex and we did not find a clear period in the 29 spectra we considered so far. This is presumably due to the rather rapid rotation that smears out the variability due to pulsation in the line profiles. Indeed, this star has the broadest lines of all the single stars in the sample.

3.2.5. HD 69144

The star HD 69144 turns out to be a single-lined spectroscopic binary with a short orbital period. The radial-velocity variation has a standard error of 33 km/s. In fact, the main frequency found in the Hipparcos and Geneva photometry is not related to intrinsic variability but is twice the orbital frequency. This star could therefore be misclassified as an SPB on the basis of the period found from the Hipparcos data. On the other hand, the line profile shown in Fig. 2 is clearly asymmetric and gives evidence of the presence of moving subfeatures. That such features are indeed present becomes clear when we look at a time series of the obtained spectra. The profiles that were gathered for this star in the course of 1996 are already shown in Aerts et al. (1998) and we will not repeat such a figure here. All this clearly shows that we are dealing with a pulsating star in a short-period circular orbit. We refer to Aerts et al. (1998) and to De Cat et al. (in prep.) for respectively a preliminary and a definite description of the orbit and of the residual radial velocity after the orbital motion has been subtracted.

3.2.6. HD 85953

HD 85953 is one of the few stars for which at least two frequencies are found in the Hipparcos photometry: 0.2662 c/d and 0.2190 c/d. These frequencies correspond to periods that are among the longest found for the stars in the our sample. The main frequency 0.2662 c/d is also recovered in the Geneva photometry and in the radial velocity. Phase plots for this frequency are shown in Fig. 10. The peak-to-peak variation of the radial

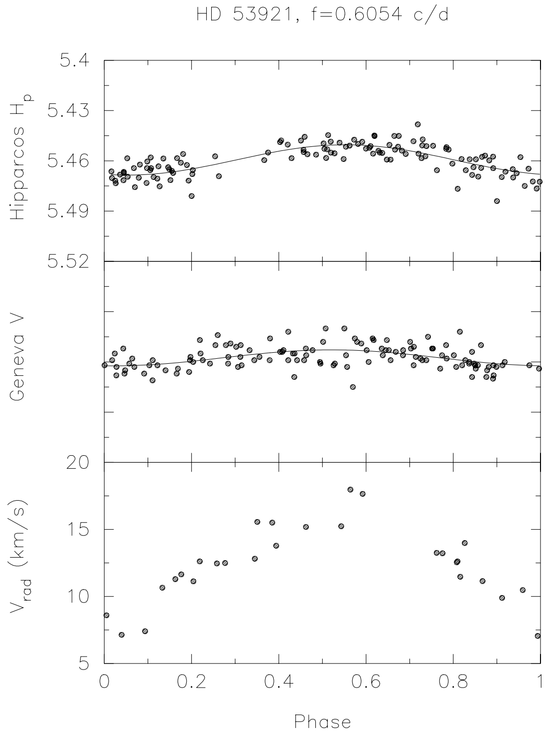

Fig. 8. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 53921 for the frequency 0.6054 c/d

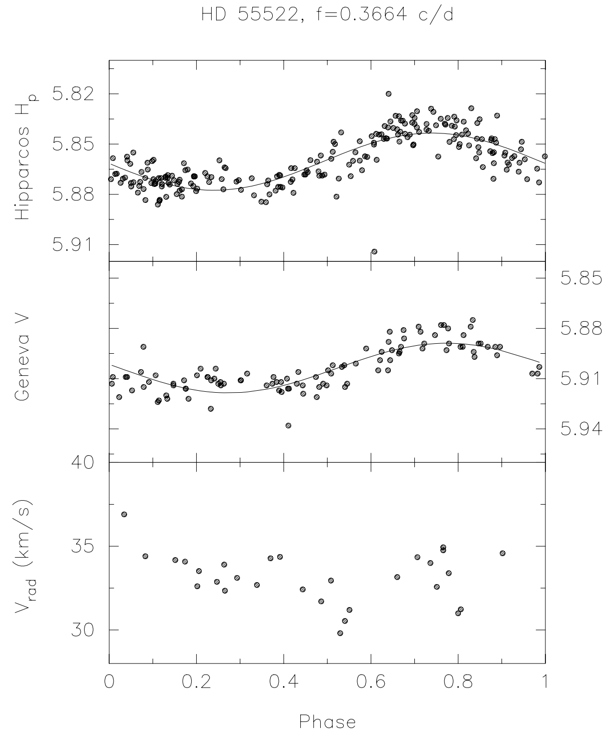

Fig. 9. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 55522 for the frequency 0.3664 c/d

velocity amounts to some 10 km/s. The line-profile variations are rather complex, as can be seen on Fig. 2.

HD 85953 is the hottest star among our target list. It is the only star that is situated in the common instability strip of the SPBs and β Cep stars. As such, it is possible that short-period p-modes are excited in this object, besides the long-period g-modes for which we have found evidence so far. The simultaneous occurence of p- and g-modes in a star is very interesting from a theoretical point of view. A thorough analysis of our total data set should give us an indication if p-modes are also excited in this star.

3.2.7. HD 92287

HD 92287 was considered as an SPB candidate by Waelkens & Rufener (1985), who recovered the same main frequency of 0.681 c/d in their photometric data of two different seasons. However, they regarded the amplitude too small to be significant, especially since much additional noise was present in the data. Therefore, the star was no longer included in their target list of SPBs.

The frequency found by Waelkens & Rufener is close to the one deduced from the Hipparcos photometry and turns out to be connected with the orbital motion of this star. Indeed, our line-profile variations lead to a standard deviation of 40 km/s for the radial velocity and clearly indicate binarity. The orbital period of the circular orbit is 2.9 days.

In the meantime, more Geneva data have been accumulated and a period analysis of the data available until July 1997 reveals a first frequency of 0.2148 c/d. This frequency is also recovered from the Hipparcos data after prewhitening with twice the orbital frequency. It is also found in the residuals of the radial-velocity after subtraction of the orbital radial velocity (De Cat et al. in prep.). A phase plot of the Hipparcos and Geneva data for 0.2148 c/d can be found in Fig. 11.

3.2.8. HD 131120

For HD 131120 we recover the same main frequency of 0.6374 c/d in the Hipparcos and Geneva photometry and in the radial velocity (see Fig. 12). The photometric amplitude amounts to 22 mmag peak-to-peak in the Geneva filter, while the radial velocity has a large peak-to-peak amplitude of 9.2 km/s. The profiles are broad and seem to be dominated by a single period. A sine fit to the radial velocity curve for the frequency 0.6374 c/d explains already 90% of the variability. The time span of the data is 332 days and we considered 59 spectra so far. HD 131120 is the only SPB so far for which we are able to determine the phase difference between the photometric and the radial-velocity variation in an accurate way. This difference is 0.28 for the Geneva V filter.

It is fairly interesting to find an SPB with a single mode, since theoretical considerations predict multiperiodicity in these stars. Moreover, this star is an interesting object because it is the second hottest in the sample (contradicting the spectral type B7II/III listed in the BSC) and is also situated close to the β Cep instability domain. A more detailed analysis of our full data set

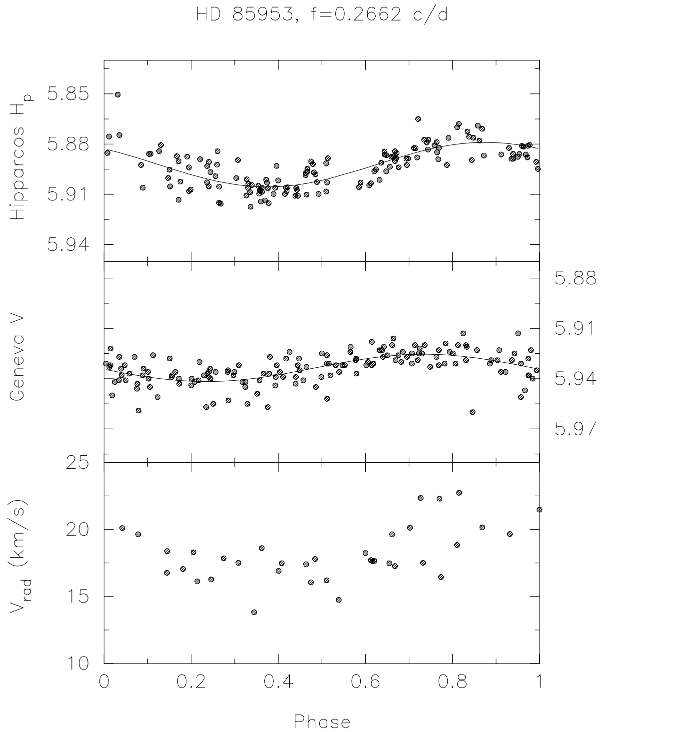

Fig. 10. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 85953 for the frequency 0.2662 c/d

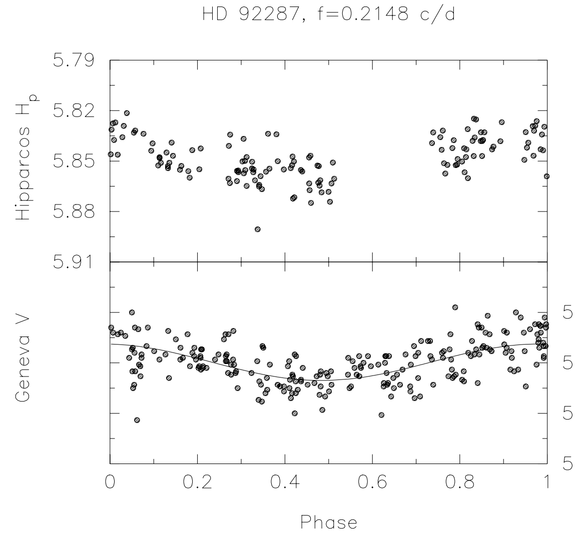

Fig. 11. Phase diagram of the Hipparcos (*top*) and Geneva (*bottom*) data of the binary HD 92287 for the main frequency of the intrinsic variation found from the Geneva data. The Hipparcos data lead to a frequency connected with the orbital motion

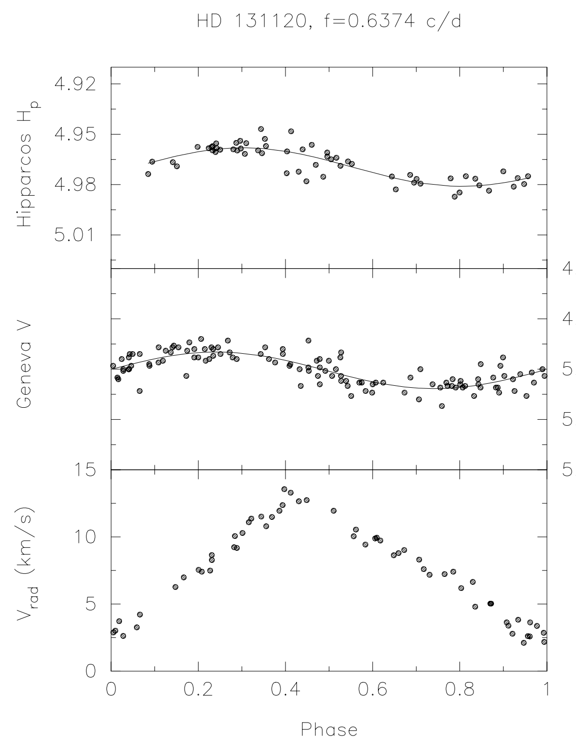

Fig. 12. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 131120 for the frequency 0.6374 c/d

should reveal whether or not the star is multiperiodic and if so, if the secondary pulsation modes consist of p- or g-type pulsations.

3.2.9. HD 138764

This star is an SPB with sharp line profiles and thus a slow rotator. The frequency that we find in the radial velocity differs from the one found in the Hipparcos and Geneva photometry, although the main photometric frequency of 0.7945 c/d also explains a large part of the variability in the radial-velocity curve (63%, see Fig. 13). HD 138764 exhibits one of the largest photometric peak-to-peak variation of the Hipparcos SPBs. It is also one of the few SPBs for which multiperiodicity was found in the Hipparcos photometry. The second frequency is 0.6371 c/d.

3.2.10. HD 140873

HD 140873 is listed as a spectroscopic binary with an orbital period of 39 days in the BSC. We indeed find a standard deviation of 17 km/s in the radial velocity and clear shifts of the lines in the spectra, confirming its binary nature. The Si II line profiles are very broad (see Fig. 2). At first we thought that a very strong bump passed through the lines, but this turns out to be the Si II line of the secondary. Indeed, there is a clear signature of the secondary in our spectra. We find some 10 sharp lines that originate from the companion. As such, HD 140873 is the second double-lined spectroscopic binary in our sample.

We obtained 29 spectra during the first year of monitoring. This is not sufficient to resolve the orbital period. We refer to De Cat et al. (in prep.) for an analysis of the complete spectroscopic data set and the determination of the orbital parameters. In the Geneva photometry, we find a one-day alias of the frequency determined from the Hipparcos data. We adopt the Hipparcos result of 1.1515 c/d here, because it is based on a larger number of data points. The Hipparcos data lead to a possible second frequency of 1.1413 c/d but the reality of this mode has to be

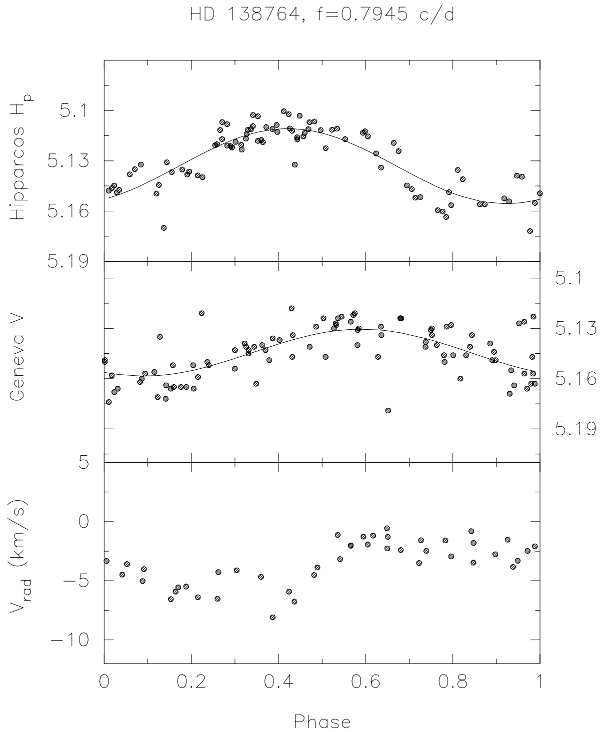

Fig. 13. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 138764 for the frequency 0.7945 c/d

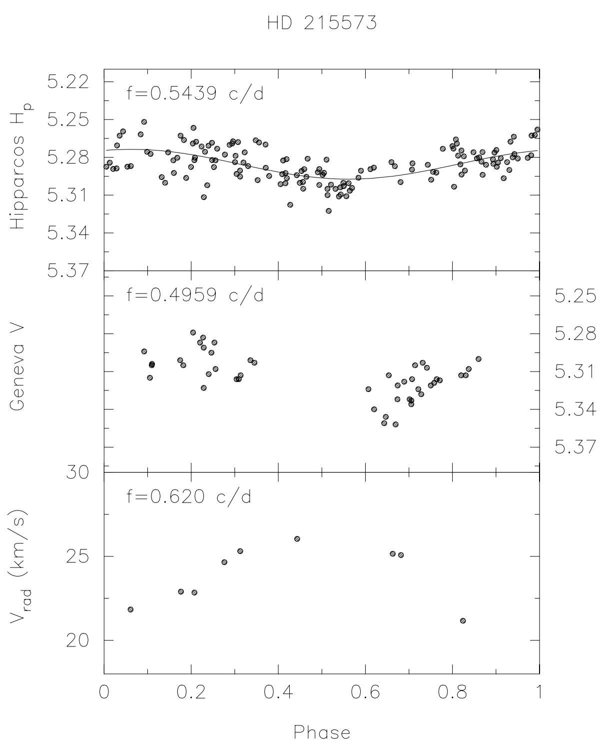

Fig. 14. Phase diagram of the Hipparcos (*top*), Geneva (*middle*), and radial-velocity (*bottom*) data of HD 215573 for the main frequency of the variation, which is different in each data set. The used frequencies are indicated in each panel

confirmed by our complete Geneva data set before we state definitely that the star is multiperiodic.

Together with HD 24587, HD 140873 has a main pulsation mode with a period shorter than a day. All other SPBs in our sample have pulsation periods longer than a day. There is no signature of the binarity in the photometry.

3.2.11. HD 169978

The star HD 169978 is the only star in our sample of which we have some doubts about its SPB nature. Indeed, our radial-velocity data clearly point out that it is a single-lined spectroscopic binary with a very short orbital period of 1.7 days. The orbit is circular (see De Cat et al., in preparation). The frequency found in both the Hipparcos and the Geneva photometry is twice the orbital frequency. Unlike in the case of HD 69144, the line profiles do not show clear asymmetries or moving subfeatures. The star could thus very well be misclassified as an SPB by Waelkens et al. (1998). On the other hand, there is some indication of a few secondary candidate periods in the Hipparcos photometry, but the amplitudes are all very small. A detailed analysis of the complete Geneva and radial-velocity data should allow us to decide whether or not this star is another SPB in a binary. If this is the case, then it is a very interesting object from a point of view of tidal effects since the two stars must be very close to each other. It is moreover a fairly rapid rotator.

3.2.12. HD 215573

HD 215573 is the only star for which we find a clearly different frequency in both photometric data sets. Moreover, the radial velocities give rise to yet another main period. The phase diagrams of the data for the most significant frequency in each of them are shown in Fig. 14. The Hipparcos frequency is the only one that can be trusted so far since the Geneva and spectroscopic data are not yet numerous enough to definitely accept the periodicity found from them. On the other hand, the radial velocities are not compatible with the Hipparcos period but they do seem to exhibit a clear variation. We have to await our complete data sets obtained during different seasons to disentangle the frequency spectrum of this star. We are in any case dealing with a slow rotator.

4. Discussion of the preliminary results

Our spectroscopic data gathered in the course of the first year of follow-up monitoring have revealed the existence of line-profile variability, with time scales expected from theoretical calculations of SPB-type pulsations, in the five previously known SPBs and in eleven of the twelve candidate SPBs that were discovered by means of the Hipparcos photometry. Our ground-based follow-up data of the latter objects are thus fully compatible with their classification as SPBs for all but one of them, the one exception being a binary star with an orbital period of the order of days. A frequency analysis of the radial-velocity variations shows that the dominant frequency in the spectra coincides with the frequency derived from the Hipparcos and the Geneva photometry for most of the selected stars.

Smith (1977) was the first one who detected line-profile variability with periods somewhat less than a day in a group of 8 stars with spectral types ranging from O8 to B5. These stars were chosen as targets because they surround the β Cep stars in the HR diagram. Smith et al. (1984) labeled them as "53 Per" stars according to the best studied member of the group. In the meantime, it has become clear that the coolest line-profile variables among Smith's sample are situated in the SPB instability strip and fulfill all the conditions to be a member of this established class of high-order g-mode pulsators. Our current study indicates that all SPBs exhibit line-profile variations. The hottest (i.e. O-type) 53 Per stars among Smith's list have a different, not yet well understood, pulsational nature. We refer to Fullerton et al. (1996) for an overview of the occurence of line-profile variability among O-type stars.

Interestingly, many of the Hipparcos stars that were observed tend to be broader-lined than the previously known SPBs, and these stars present more subfeatures in their line profiles. For the fastest rotators we find that the rotation periods are of the same order of magnitude as the pulsation periods, implying that the theoretical framework to study these pulsations must be based on a rotating star, i.e. cannot rely on velocity expressions in terms of one spherical harmonic.

The star HD 85953 is situated in the hot-temperature part of the SPB instability strip, in the lowest part of the instability domain of the β Cep stars. Variable stars that appear in the common instability domain of the SPBs and β Cep stars are good candidates for the appearance of both p- and g-modes. It is not clear to us yet whether or not HD 85953 also exhibits β Cep-like pulsations (i.e. p-modes), besides the long-period g-mode that we were able to detect so far. We should be able to make more definite conclusions about this once the gathering of our data has been completed. The same remark is also relevant for HD 131120, although it is situated close to, and not in, the β Cep strip.

HD 123515 was already known to be an SPB in a binary. Our spectra show that four of the candidate SPBs found by Hipparcos and two previously known SPBs also belong to a multiple system. We have not been able yet to determine the orbital parameters for all the binaries, but we do find that at least three of them have orbital periods of the same order of magnitude as the pulsational periods. A more thorough analysis should point out whether or not the binary nature of these stars has an influence on their pulsational behaviour.

It also turns out that the most complicated line-profile variations occur in the binaries with a large rotational velocity, while all stars with limited broadening do not exhibit moving bumps. This suggests that it is the rotation, and not the binarity that results in a particular spectrum of observed excited modes.

Baade (1989) has undertaken a search for line-profile variability among 22 bright stars of spectral type B8 – B9.5 and found a null result. The coolest SPB among our sample is HD 123515, with an effective temperature of about 12 000 K. All other confirmed SPBs have effective temperatures hotter than 13 500 K. We did discover a few photometrically variable B8 – B9 stars with periods in the range of 0.1–0.4 days by means of the Hipparcos data. These stars are situated below the theoretical SPB instability strip and have periods that are shorter than those predicted by theory. A forthcoming paper will be devoted to the photometric variability of these stars. We also plan to investigate whether or not these stars are line-profile variables.

5. Future plans

At present, we are still completing the reduction process of all the gathered follow-up photometric and spectroscopic data. In total, we will have covered 21 weeks spread over a year with photometry and some 10 weeks spread over two years with spectra. This should allow us to derive the periods and the character of at least the dominant modes more accurately in the near future. We plan to identify the modes with both the moment method (Aerts 1996), which is an accurate identification technique based on line-profile variations in the case of slow to moderate rotators, and with the method of photometric amplitudes (Heynderickx et al. 1994). Other follow-up observations can then be planned according to the first results.

We also mention that we recently have been allotted telescope time by the Observatoire de Haute-Provence in France for a similar spectroscopic monitoring programme devoted to the brightest northern candidate SPBs discovered by Hipparcos. These observations have started in February 1998 and will be completed by the end of 1998.

Another interesting issue of our study is the inclusion of both a λ Eri star and a shell star in our target list. Taking into account their Be characteristic, both stars are slow rotators with vsini$\leq$200 km/s. We did not describe the preliminary results for these stars here, since they were not classified as SPB by Waelkens et al. (1998) because of their different nature. On the other hand, they were both found to be variable B-type stars with periods in the SPB range from the Hipparcos mission and they do exhibit line-profile variations that are at first sight not markedly different from those of the SPBs described in this paper. In this sense, the comparison between their variability and the one of the SPBs can give important clues to the understanding of the Be nature of the stars. We will devote a special paper to the analysis of our complete gathered data set for these two objects.

Our final aim is to disentangle the frequency spectrum of the SPBs and to identify the modes. If we succeed in doing so, important issues such as the determination of accurate masses, the extent of convective overshooting, and the internal rotation law can be determined with high precision. Hipparcos provides us with an opportunity to select a sample of intermediate-mass early-B type stars for which we can obtain such results. In this respect, the discovery of the large amount of SPBs by Hipparcos is an important step towards the understanding of the internal structure of massive stars.

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