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# Long-Term Photometric and Spectroscopic Monitoring of Slowly Pulsating B Stars[1]

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**Abstract.** We review the current status of our long-term monitoring project on slowly pulsating B stars that we started in the course of 1996 and that was recently completed as far as the first part of our plan is concerned. In total, we have selected 17 southern and 8 northern stars. The idea is to fully exploit our current data in the near future and to select the most interesting targets for further very-long-term follow-up monitoring. A first conclusion is that half of the southern targets turn out to be spectroscopic binaries. Some of these have circular orbits and periods of the same order of magnitude as the intrinsic pulsation period(s) of the primary. The eccentric binaries have periods ranging from 12 to 460 d. For most stars the photometric behaviour is dominated by the same frequency as the intrinsic spectroscopic variability. Multiperiodicity in the expected frequency range is found for almost all stars. Two objects, however, turn out to have only one dominant pulsation mode.

## 1. Introduction

We recently not only addressed the fact that slowly pulsating B stars (hereafter called SPBs) appear frequently in our close neighbourhood (Waelkens et al., 1998), but we also showed that the position of these SPBs is fully compatible with the theoretical instability strip recently calculated by Pamyatnykh (1999). Our interest in the SPBs originates from the fact that they are massive stars to which seismological principles can be applied.

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[1]The follow-up data for the southern stars were gathered with the Swiss Telescope of the Geneva Observatory and with ESO's CAT telescope, both at La Silla, Chile; those of the northern stars were obtained with the 1.52-m telescope of the Haute-Provence Observatory in France

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Theory predicts that many high-order g modes with periods of the order of days should be excited in the SPBs (Dziembowski, Moskalik, & Pamyatnykh 1993; Gautschy & Saio 1993). At present, however, this theoretical result is hardly confronted with observational facts. Indeed, a catalogue of excited modes for a large sample of SPBs, unbiased regarding spectral type, rotational velocity and intrinsic periodicity, is not yet available. This lack has everything to do with the large observational effort that is needed to derive frequencies and modes in SPBs. Data with a time span of at least several years are needed to disentangle the frequency behaviour. Our aim first of all is to compose such a catalogue and, later on, to apply seismology to B-type stars.

This paper is organised as follows. Details on our long-term photometric and spectroscopic monitoring are given in Section 2. In Section 3, we present preliminary results for some of the targets of our observational programme. Finally, our future plans regarding the analyses of our current data and the planning to obtain subsequent follow-up data are given in Section 4.

## 2. Observations

We have selected all the candidate SPBs from the list given by Waelkens et al. (1998) with visual magnitude up to 6. To this target list, we have added the 5 brightest SPBs found earlier by Waelkens (1991). This results in 30 stars: 22 southern and 8 northern targets.

For all these stars, we have taken high-resolution spectra of the Si II $\lambda\lambda$ 4128, 4130 Å doublet. The reason for this choice is that these lines are clearly present for spectral types between B2 and B9. Due to the choice of this wavelength region, we had to delete 5 stars from our list, since they have a $v \sin i$ larger than 200 km s$^{-1}$, implying that the Si II doublet is blended.

Table 1. Stellar parameters of the northern SPBs that were considered for long-term spectroscopic monitoring. The spectral type and $v \sin i$ (km s$^{-1}$) were taken from the BSC. The period listed in the 8th column is the main period found from the Hipparcos photometry.

| Star | $m_V$ | SpT | log $T_{\rm eff}$ | log $g$ | log $L/L_\odot$ | M [M$_\odot$] | P [d] | $v \sin i$ |
|---|---|---|---|---|---|---|---|---|
| HD 1976 | 5.6 | B 5 IV | 4.19 | 4.05 | 2.80 | 4.8 | 1.06 | 230 |
| HD 21071 | 6.1 | B 7 V | 4.15 | 4.30 | 2.26 | 3.7 | 0.84 | 43 |
| HD 25558 | 5.3 | B 3 V | 4.22 | 4.18 | 2.78 | 4.9 | 1.53 | 51 |
| HD 28114 | 6.1 | B 6 IV | 4.15 | 3.98 | 2.66 | 4.3 | 1.08 | 25 |
| HD 147394 | 3.9 | B 5 IV | 4.17 | 4.04 | 2.66 | 4.4 | 1.25 | 32 |
| HD 182255 | 5.2 | B 6 III | 4.15 | 4.22 | 2.36 | 3.9 | 1.26 | 40 |
| HD 206540 | 6.1 | B 5 IV | 4.14 | 4.08 | 2.47 | 4.0 | 1.44 | 20 |
| HD 208057 | 5.1 | B 3 V | 4.22 | 4.10 | 2.88 | 5.1 | 1.25 | 152 |

For a detailed description of the data and of the physical parameters of the southern SPBs we refer to Aerts et al. (1999c), but we mention here that the high-resolution spectroscopy performed with the CAT consists of 10 weeks

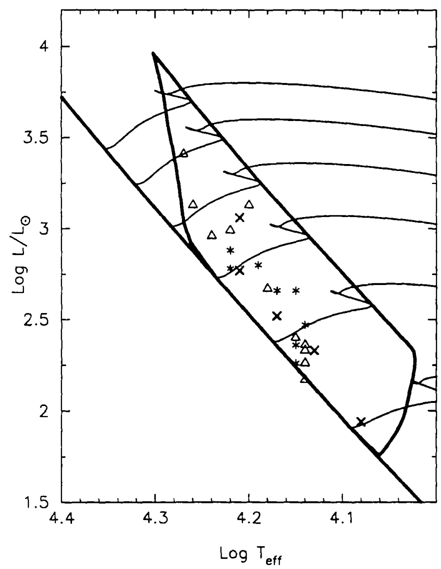


Figure 1. The position of the 24 SPBs (×: SPBs discovered by Waelkens (1991), △: southern Hipparcos SPBs, ∗: northern Hipparcos SPBs) is confronted with the theoretical instability strip determined by Pamyatnykh (1999).

of monitoring with a total time span of 2 yr, while the Geneva photometry spans at least 1 yr. For the northern stars, we were not able yet to perform dedicated photometry. This will be done as soon as the new 1.2-m Mercator telescope that our institute is building becomes operational on La Palma (end of 2000, web-page: `http://obswww.unige.ch/~davignon/`). However, some observations exist in the Geneva system. These are used to calculate the stellar parameters as explained in Aerts et al. (1999c). The results are listed in Table 1, together with the main period derived from the Hipparcos photometry and $v \sin i$ as listed in the BSC. The spectra of the northern SPBs were obtained with the spectrograph Aurélie at OHP and are currently still in the reduction process, but we can already conclude to have detected line-profile variability in all targets. These data were taken during 8 weeks and have a total time span of 16 months.

## 3. Preliminary Results

First of all, we were able to confirm the SPB nature of all but one target, the latter being an ellipsoidal variable with an orbital period of 1.7 d. We place the 24 confirmed SPBs in the HR diagram (Fig. 1) and confront their position with the theoretical instability domain determined by Pamyatnykh (1999). The strip is based on OPAL G93/21 opacities (Iglesias & Rogers 1996) for a composition X = 0.70, Z = 0.02. No overshooting was considered. The evolutionary tracks for 3, 4, 5, 6, 7, and 8 M$_\odot$, as well as the instability strip, were kindly made available to us by Dr. Pamyatnykh. It can be seen from Fig. 1 that our targets nicely fill the strip and will thus allow us to present an overview of SPB characteristics across the whole instability domain.

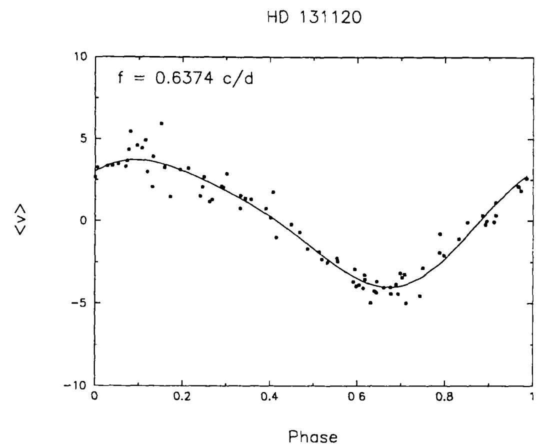


Figure 2. The observed (dotted) first moment (in km $s^{-1}$) of the SPB HD 131120 is compared with a model for the frequency 0.6374 $d^{-1}$ and its first harmonic.

A striking observation, which became more and more obvious as our long-term project continued, is that about half of the southern targets are spectroscopic binaries. Two SPBs were already known to be a binary, but for the well-known SPB HD 177863 (Waelkens 1991), e.g., this was a new result. For the new SPB HD 24587 we needed more than one year of spectroscopy to decide upon its binary nature and to find the orbital parameters. The orbital solution for this star is given in Aerts, De Cat, & Eyer (1999b), where the importance of long-term monitoring is pointed out. We refer to the poster by De Cat & Aerts (2000) for an overview of the orbital parameters of the binaries, but we note that several ellipsoidal variables with orbital periods of the same order of magnitude as g-mode periods are among the list. In fact, for those stars, the periods derived from the Hipparcos photometry are connected to the orbit. All of these stars, however, turn out to have a main component that exhibits intrinsic variability as well. A paper on the binaries among our SPB sample will be published soon (De Cat et al., in preparation).

We are currently performing frequency analyses of all the data. For most SPBs, we find multiple signals in the expected frequency ranges in the observables. As an example we mention that we find consistent results between the photometry and spectroscopy for the well-known SPB *o* Velorum (HD 74195). Waelkens (1991) already detected 5 frequencies for this star in his Geneva photometry. We recover, respectively, the first two, the fourth and an additional new one in our line-profile variations of this star. This example shows that the objective which we had when starting this project (see Aerts et al. 1999c) can be fulfilled when a sufficient number of spectra are gathered.

We find two SPBs, HD 131120 and HD 42927, with a clearly dominant mode for which no other variability is found. The latter star is not among our sample for long-term spectroscopic follow-up since it is optically fainter than all the targets ($m_V = 6.7$), but we monitored it photometrically because it turns out to be one of the two (out of 163) pulsating B stars surrounded by circumstellar dust (Aerts et al., 1999a), and is therefore an interesting object in the search for Vega-type stars. The phase curve of the first moment (see e.g. Aerts, De Pauw, & Waelkens (1992) for a definition of the moments of a line profile) of

HD 131120 is shown in Fig. 2. We find only one frequency in the data for this star, but we remark that the radial velocity is non-sinusoidal so that the first harmonic of the frequency is necessary to obtain a good fit.

One star, HD 85953, is situated in the common part of the $\beta$ Cep and SPB instability strips. So far, we detected only frequencies in the range of the g-mode domain and we do not find evidence for the excitation of a p mode in this star.

We finally point out that the equivalent width (EW) changes of the SPBs deserve some attention. We find relative EW variations of 5 – 35%, which is in general much larger than those detected for $\beta$ Cep stars (De Ridder & Aerts 2000). The EW variability does not exhibit any clear periodicity comparable with the variability in the radial velocity. These findings will be explored in more detail in the near future (De Ridder et al., in preparation).

## 4. Conclusions and Future Work

The preliminary results described in the previous section already contain important valuable information for theorists working in the field of the excitation mechanism in hot stars. Our finding that dominant g modes appear in some stars should tell us something about the selection of the excited modes. Also, the large fraction of spectroscopic binary SPBs among our sample raises the question whether the binarity is of importance for the excitation and selection of the modes in these stars.

We will continue our detailed analyses of all the data that we have gathered in the past three years. In particular we will search for frequencies in the combined datasets, i.e. in the Geneva and Hipparcos photometry and at the same time in the moments of the line profiles.

Next, we will identify the modes that are clearly present in the data. This will be done with both the moment method (Aerts 1996), which is an accurate identification technique based on line-profile variations and with the method of photometric amplitudes (Heynderickx, Waelkens, & Smeyers 1994). We have already applied the latter method for the main mode of half of the stars; our preliminary conclusion is that higher-degree modes ($\ell > 2$) are excited in the Hipparcos SPBs. This might explain why these stars were not found by means of ground-based surveys.

Our analyses will point out the best targets to perform very-long-term spectroscopic follow-up monitoring. This will be started in the beginning of the next century with the new spectrograph CORALIE attached to the Swiss telescope on La Silla, which is in fact a twin of the Mercator telescope. Our final aim is to disentangle the frequency spectrum of the selected SPBs and to identify their pulsation modes. If we succeed in doing so, important issues about the internal structure of these stars can in principle be addressed.

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## Discussion

*Nancy Evans*: Do any of the SPBs belong to the chemically peculiar stars in that area of the HR diagram?

*Conny Aerts*: One star is known as a Si star, but the others are normal B-type stars.

*Giuseppe Bono*: Did you find any evidence of shock waves in your spectroscopic data of the SPB sample?

*Conny Aerts*: No, all the RV and light curves behave smoothly and can be explained by a superposition of multiple sinusoids and we do not encounter large amplitudes.

*Tim Bedding*: Are there any SPBs known in clusters?

*Conny Aerts*: Two of the ones discovered by Waelkens belong to the cluster IC 2391.

*Don Kurtz*: Åke Nordlund showed at this conference (see p. 362 in these proceedings) that turbulence distorts the line profiles extensively. How does that effect mode identification from line-profile variations?

*Conny Aerts*: I do not believe that turbulence effects are important for the mode identification process that we apply to these hot B stars. The reason is that the moment method uses quantities that are normalised with respect to the equivalent width of the lines. At present, we still assume a Gaussian intrinsic width but we plan to generalise our identification code for a more realistic intrinsic profile derived from a model atmosphere. To answer your question with certainty, we would have to perform simulations using intrinsic profiles that include turbulence effects and see how this affects our method. This is something we can do once the new version of our identification method is out.