SLOWLY PULSATING B STARS : NEW INSIGHTS FROM HIPPARCOS

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Abstract. The photometric experiment on board of Hipparcos has discovered, among other types of variables, a large amount of new Slowly Pulsating B Stars. We have selected the fourteen brightest stars of this sample, together with five previously known Slowly Pulsating B Stars, for long-term spectroscopic and photometric monitoring. The selected stars have spectral types ranging from B 2 up to B 9 and are thus nicely spread across the instability strip. We here present the results of a preliminary analysis of our data and point out that our sample is unique in the sense that it allows us to perform seismology of massive early-type stars.

1. Selection of the program stars

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. (1997) 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 (1997).

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. Besides this, all the newly discovered members of the group deserve to be studied for the simple reason that we have for the first time a large, unbiased sample of SPBs 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

F.-L. Deubner et al. (eds.), New Eyes to See Inside the Sun and Stars, 295–298.

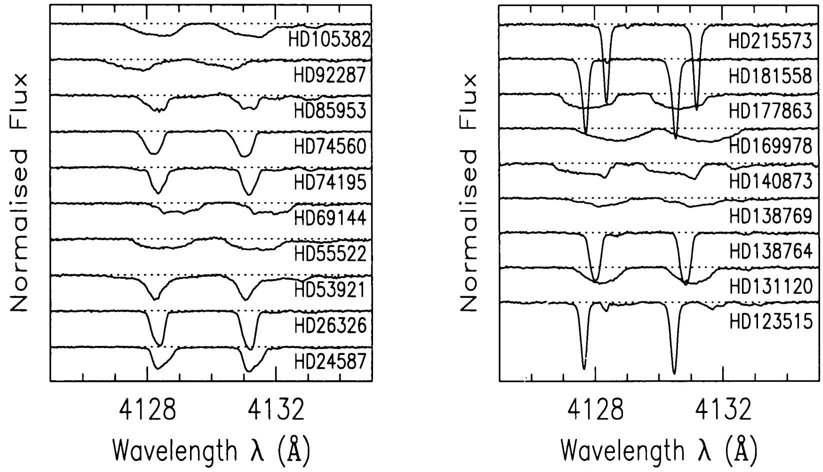

Figure 1. One arbitrarily chosen spectrum of the Si II doublet centered around 4130Å for each of the 19 target SPBs. The rotational velocities derived from our data range from 10 to 100 km/s

their variations by means of line profile studies. Moreover, accurate photometry can be performed with small telescopes.

We have selected the 14 brightest southern Hipparcos SPBs, together with 5 bright ones previously found by Waelkens (1991), for long-term photometric and spectroscopic monitoring. These stars have spectral types ranging from B 2 up to B 9 and are thus well spread across the instability domain to have a general overview of the pulsations in the complete temperature range of SPBs. The photometric data are gathered with the Swiss Telescope of the Geneva Observatory and the high-resolution line profiles are taken with the CAT telescope of the European Southern Observatory, both situated at La Silla, Chile. We started our monitoring in 1996 and have been allotted telescope time with both instruments for this year and in 1998.

2. Preliminary analysis of our data after 6 months of monitoring

We did not obtain photometric data of the SPBs in the course of 1996 and therefore focus on the spectroscopy here. Line-profile variations were observed in March, April and July 1996, each time during 7 nights. We have obtained between 10 and 70 high-resolution, high S/N spectra of the Si II triplet centered around 4130Å for 16 of the targets (for 3 stars, we only obtained a few spectra during the first year). Our spectroscopic data gathered in the course of 1996 have revealed the existence of line-profile variability with the expected time scales in the 5 previously known SPBs and in all 14 candidate SPBs that were discovered by Hipparcos, confirming the pulsational nature of the latter.

A typical spectrum for each of the targets is shown in Fig. 1. HD 74195, HD 74560, HD 123515, HD 177863, and HD 181558 were discovered by means of ground-based photometry by Waelkens (1991), while the others are found with Hipparcos. HD 105382 and HD 138769 are listed in the BSC as respectively Be and shell star, but were clas-

https://doi.org/10.1017/S0074180900238795 Published online by Cambridge University Press

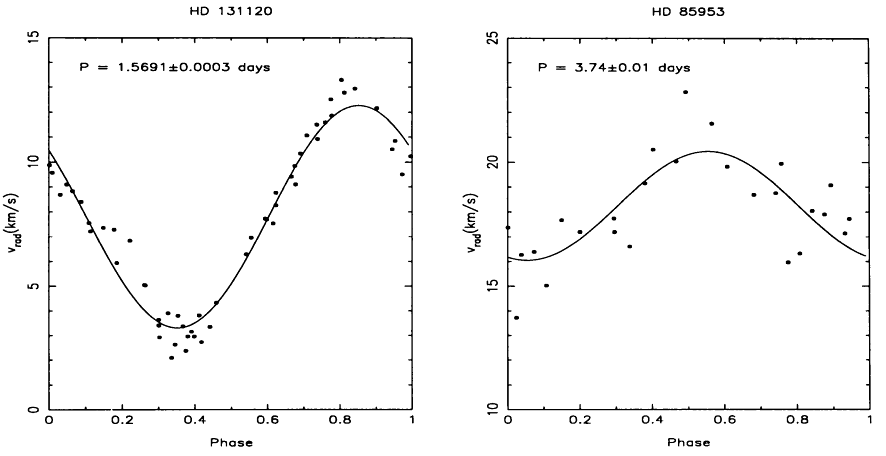

Figure 2. Radial velocities derived from our Si II spectra for the two SPBs that are situated in the common part of the β Cep and SPB instability strip (see Waelkens et al. 1997). The dots are the observations while the full line is a fit for the period indicated in the graph. In both cases, this period agrees with the one found from the Hipparcos photometry

sified as SPB by Waelkens et al. (1997). We observed Hα of the two stars and found variable emission in the case of HD 105382, but absorption for HD 138769. Their Si II line-profile variations are similar to those of the other SPBs. We included them in our sample because it is important to find a link between variable Be stars and confirmed pulsators.

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. This probably means that rotation is accompanied by higher-degree modes, which are hardly detected in the photometry. We derive rotational velocities between 10 and 100 km/s from our data, but these may very well be overestimates since we are not yet able to estimate the total pulsational broadening. For the fastest rotators this nevertheless means 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.

Another result is that the equivalent width variations are large (about 15%) and point towards important temperature variations during the pulsation cycle. Theoretical models that take into account temperature variations in line-profile variations are up to now based on adiabatic pulsation theory. Our data shows that there is a great need to generalise these models to non-adiabatic pulsations. We are currently working on such a generalisation.

As an example, we show in Fig. 2 a phase diagram of the radial-velocity variations for the two SPBs discovered by Hipparcos that are situated in the common part of the instability domain of the β Cep stars and the SPBs (see Waelkens et al. 1997). The main frequency found in our data is the same as the one found in the Hipparcos photometry and confirms their SPB nature. HD 131120 clearly has one dominant mode, while HD 85953 probably is multiperiodic. It is not clear to us yet whether or not these stars also exhibit β Cep-like pulsations (i.e. p modes).

https://doi.org/10.1017/S0074180900238795 Published online by Cambridge University Press

A frequency analysis of the radial-velocity variations shows that for ten of the fourteen Hipparcos SPBs the dominant frequency coincides with the frequency derived from the Hipparcos photometry or multiples of this frequency. The latter case appears when the target turns out to be a binary. HD 123515 was already known to be a binary. Our spectra show that four of the SPBs found by Hipparcos and one previously known SPB also belong to multiple systems and have orbital periods of the order of days. All the binaries with short orbital periods turn out to have large rotational velocities and complicated line-profile variations. This suggests that the binarity results in a particular spectrum of excited modes. For the determination of the orbital parameters of some of the binary SPBs, we refer to Aerts et al. (1997).

3. Future prospects

At present, we are still continuing the gathering of photometric and spectroscopic data. We expect to have a total time base of at least two years for the spectroscopy and of one year for the photometry. In total, we will have covered 21 weeks with photometry and some 10 weeks with spectra. This should allow us to derive the periods and the character of at least the dominant modes. 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.

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 overshoot, 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.

Acknowledgements

CA acknowledges a postdoctoral fellowship of the Fund for Scientific Research of Flanders. A special thank is addressed to Michel Grenon and to Laurent Eyer for involving us in the classification of the variable B-type stars found with Hipparcos and for fruitful discussions. We are grateful to the Observatoire de Genève and to the European Southern Observatory for the generous awarding of telescope time to make this long-term project possible.

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