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Multimode Detections from Surveys

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Abstract. In this study we present an overview of the search for multiple frequencies in variable Be stars from surveys. We review the recent ground-based photometric surveys and conclude from them that multiperiodicity is not detected. The photometric experiment on board Hipparcos, on the other hand, does allow us to derive multiple periods for a few Be stars. We present the results of our frequency searches in the Hipparcos data for 50 λ Eri stars.

Further we review the recent spectroscopic campaigns dedicated to some stars. It seems that all of these campaigns point to multiperiodic phenomena, although for most of them the time base is insufficient to derive the periods with high accuracy. Moreover, the spectroscopic periods are often not the same as those found from the photometry. This clearly demonstrates the necessity of long-term simultaneous photometric and spectroscopic campaigns. We present the preliminary results of such a campaign for the λ Eri star HD 105382.

We close with reflections on the cause of the variability observed in the λ Eri stars and on the best viewpoint for further research in this area.

1. Introduction

One of the key questions in the research on Be stars is what role non-radial pulsations play in the onset and the maintenance of the circumstellar discs around these stars. This was one of the open questions after the colloquium held at Juan-les-Pins (Baade & Balona, 1994), which is still open today. The subject receives a lot of attention at this meeting as well. A question directly related to this problem is : *"what is the cause of the periodic variability that appears in optical data of a large fraction of the Be stars?"* (the so-called λ Eri stars, Balona 1990). One of the main differences between the two current competing models, namely rotational modulation and non-radial pulsations, is that the former model only allows the presence of periods related to the rotation period of the stars while general multiperiodicity is compatible with the latter model.

Some current studies of the temporal variability of λ Eri stars prefer the pulsational model above the rotational model on the sole basis of the presence of claimed multiperiodicity. The beating between non-radial pulsation modes is an attractive idea to explain the formation of the disk of the Be stars. I stress,

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however, that the λ Eri stars consist of only a fraction of the Be stars. Moreover, no detailed theory that predicts the formation of a disk as the consequence of pulsation mode beating exists at present.

By searching in the literature to construct Table 3, it has become clear to me that the viewpoint of many authors who study line-profile variability of λ Eri stars is that the pulsational model offers a good explanation for disk formation. I believe that this view should at least be modified since none of these papers is based on data that support this idea, the only exception being the work by Rivinius et al. (these proceedings). Instead, more attention should be paid to detailed modeling in the sense of direct comparison between the derived theoretical model and the observations. Such modelling can only be done once the variability periods have been determined with high accuracy. It also became clear that the latter is achieved for only very few stars. To make general statements about the importance or irrelevance of non-radial pulsations in the Be phenomenon, it is, however, necessary to obtain detailed accurate modelling for a large subgroup of the Be stars.

As already mentioned, the accurate determination of the periods present in the variations of the λ Eri stars is a first and crucial step in the interpretation of the data. Our current study is performed in this context. An important question is: *"are the variations observed for the λ Eri stars mono- or multiperiodic?"*. I have tried to find an answer to this question on the basis of available surveys made of these stars, i.e. I have searched for clear detections of stable multiple short-period variations in Be stars. For this search I have made use first of all of available ground-based photometric surveys suited to find such multiperiodicity. Besides this, I have searched for multiple periods in the Hipparcos data base. The results based on these photometric surveys are described in the first part of this paper. In a second part the results of the search for these multimode detections are confronted with the periodicities found from ground-based dedicated spectroscopic campaigns. Such campaigns are not available yet in the form of large surveys, they are limited to a few stars. I next turn attention to a long-term photometric and spectroscopic campaign on the λ Eri star HD 105382. Finally, I give some reflections on the current status of the interpretation of the periodicity in the λ Eri stars.

2. Photometric surveys

2.1. Ground-based surveys

A first recent large systematic ground-based survey has been done by Cuypers et al. (1989) and by Balona et al. (1992) at both ESO and SAAO. They observed 39 southern λ Eri stars during several weeks and concluded that none of them has any sign of multiperiodicity in the sense of clearly detected second frequencies. They do note a lot of flickering for several among their target stars. Another result is the lack of variability beyond spectral type B 7.

A much longer-term project of Be star monitoring is presented by Sterken et al. (1996). As part of the Long-Term Photometric Variable project of ESO, they studied 15 Be stars. Four of them turn out to be periodic with periods in the range 4–93 d. The observing frequency was, however, less than once per

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day, because of which their data base is not really suited to find short-period multiperiodicity.

A yet still longer-term monitoring project concerns the photometric survey performed at Hvar Observatory which contains thousands of data points gathered during 18 years of observations (Pavlovski et al. 1997). In their study, Pavlovski et al. have mainly searched for long- and intermediate-term variations.

I conclude that only the studies of Cuypers et al. and Balona et al. were dedicated to find accurate short-term periodicities in Be stars. Their analyses show that it is very difficult to find clear multiperiodicity in ground-based photometric data of λ Eri stars. The authors conclude that the λ Eri stars are monoperiodic variables.

2.2. The Hipparcos data base

Table 1. Seven new λ Eri stars

Star	m_V	SpT	period	ampl.	frac. var.
HD 81654	7.9	B5 IV npe	3.2887 d	0.071	53%
HD 128588	9.1	B 3 V ne	5.5114 d	0.029	49%
HD 144320	9.1	B 1 V ne	2.8623 d	0.035	56%
HD 161858	7.6	B 6 V ne	4.7669 d	0.028	67%
BD+54.2790	9.7	B 0 IV n	1.5089 d	0.053	65%
BD+61.2408	9.7	B 0 III p	1.2995 d	0.077	81%
HD 220116	8.7	B 0.5 V pe	3.2864 d	0.080	59%

The photometer attached to the telescope on board the satellite Hipparcos has observed some 118,000 stars during 3.3 years. An important by-product of the satellite mission is the discovery of new variable stars (Eyer & Grenon 1997). An advantage of satellite data over ground-based data for variable star research is that the former lead to fewer 1 c/d problems compared to the latter. This particularly turned out to be useful in the case of stars that exhibit intrinsic variability with (multiple) periods of the order of days.

Waelkens et al. (1998) have classified 267 new B-type periodic variables on the basis of Hipparcos data and find that some 100 of them turn out to be Slowly Pulsating B Stars (hereafter termed SPBs, see Waelkens 1991). I found that at least seven of these 267 new B-type variables are new λ Eri stars that were not yet mentioned in the literature before. I list them in Table 1, together with their spectral type, the period I found, the corresponding amplitude and the fraction of the total consistent with this period. I searched for, but failed to find, multiperiodicity in them. This is not surprising because all of the stars are optically faint and our analyses of the SPBs has pointed out that the detection of multiple modes is limited to stars with magnitude below 7. I show the Hipparcos light curve for two of the new λ Eri stars in Fig. 1.

Hubert & Floquet (1998) have performed an investigation of the variability of 273 Be stars based on Hipparcos data. They list many new bright λ Eri stars. Moreover, they often found different periods than those listed in the literature

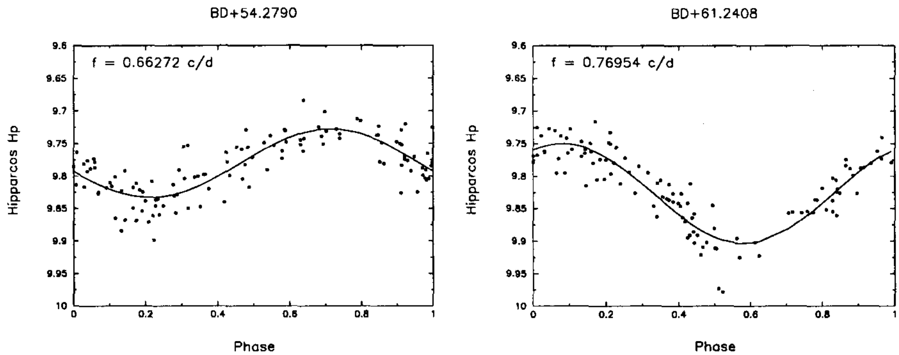

Figure 1. Phase diagrams of the Hipparcos data for BD+54.2790 and BD+61.2408. The dots are the observations while the full line represents the model given in Table 1

for already known λ Eri stars. Hubert & Floquet quote 13 candidates for multiperiodicity. I stress, however, that they did not explicitly perform frequency analyses to search for multiperiodicity but used as a sole criterion the appearance of a large amplitude in the Hipparcos photometry. However, I found that well-known multiperiodic β Cep stars and SPBs often have small amplitudes in the Hipparcos data. A re-analysis of the Hipparcos data therefore seems warranted before making explicit statements about the presence of multiperiodicity. For such a re-analysis, I consulted the lists given by Balona (1995) and by Hubert & Floquet (1998).

A prior question to answer before starting such an analysis is *"can multiperiodicity be derived from Hipparcos data?"*. The answer is *"yes"*. In the context of a long-term photometric and spectroscopic ground-based follow-up study of bright SPBs (Aerts et al. 1999), I analysed the Hipparcos light curves and compared them to the Geneva data. For the well-known SPB o Velorum, e.g., I recover the first three frequencies found earlier by Waelkens (1991) in the Hipparcos data. This points out that the Hipparcos data are suited to detect frequencies with a high accuracy. In total, I found multiperiodicity in the Hipparcos data for about half of the SPB targets considered by Aerts et al. (1999). In view of the fact that these stars are brighter than magnitude 6.5 and that multiple periods were not found in Hipparcos data of SPBs fainter than 7th magnitude, I take the latter as an faint limit of the λ Eri stars in a search for multiple modes. Since the short periods in Be stars are of the same order of magnitude as those in SPBs, I expect the Hipparcos data to have the same potential for such bright λ Eri stars as for the SPBs. A disadvantage for the Be stars, however, is the occurrence of longer-term trends in the photometry. These trends first have to be prewhitened from the data, but this process is often difficult to perform and could influence further frequency analyses. In view of this, I limited the search to λ Eri stars which show no trend in the Hipparcos data. Moreover, I selected only those stars that are clearly variable. In practice, I retained those λ Eri stars whose standard deviation is at least twice the average standard error

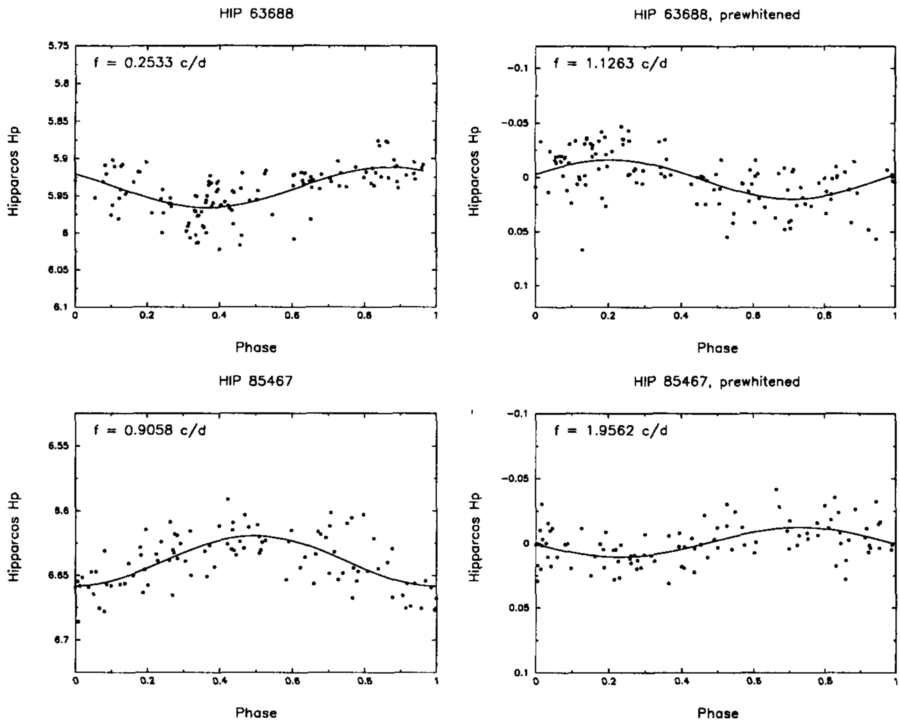

Figure 2. Phase diagrams of the Hipparcos data for HIP 63688 and HIP 85467. The dots are the observations while the full line represents the model given in Table 2

of the data. Fifty λ Eri stars, of which 29 are given by Balona (1995), fulfill the three imposed conditions and will be considered in the following period analysis.

For the 50 targets, I searched for frequencies in the range of $[0.01, 3]$ c/d, in steps of 10^{-4} c/d. I accepted a frequency when it leads to a considerable reduction of the variance fraction, when it has an amplitude which is larger than the average standard error of the data, and when it has a convincing phase diagram. The same criteria were applied after prewhitening. Based on our experience from the SPB analyses, I limited the search to two frequencies per star. The results of our analyses are as follows:

- 4 out of the 29 stars listed by Balona (1995) seem to have at least two frequencies. I list them in italics in Table 2. The star HIP 67472 is better known as μ Cen. I do not recover the frequency listed earlier in the literature from photometric studies for this star, but I find instead 0.5610 c/d. I note that this frequency is a one-day alias of the beat frequency belonging to the periods $\mathcal{P}_1$ and $\mathcal{P}_5$ recently found by Rivinius et al. (1998) from five years of spectroscopic data.

- A remarkable result from these analyses is that one almost never recovers the frequencies listed by Balona (1995), while we did recover the already known frequencies in the case of SPBs. The same conclusion was also drawn by Hubert & Floquet (1998). I paid special attention to search for frequencies in the close neighbourhood of those given in the literature. For three stars I then find fits of only a slightly lower quality than those obtained from an unbiased frequency search. In all other cases, the literature frequencies are not present in the Hipparcos data. This either means that the periods of λ Eri stars derived from ground-based data (typically spread over a few weeks) have to be treated with caution, or that the long time-span of the Hipparcos mission implies the presence of longer-term effects other than clear trends (e.g. amplitude variations) that prevent accurate period determination. I note that frequency determinations for SPBs based on only a couple of weeks of ground-based data often lead to wrong frequencies. This is the case when multimodes with comparable amplitudes and periods are excited.

- 7 of the 21 additional λ Eri stars listed by Hubert & Floquet (1998) fulfill our criteria of having at least two frequencies. The phase diagrams for two of them are shown in Fig. 3 and they are listed in roman in Table 3.

Table 2. 11 λ Eri stars for which I find evidence of a second period in the Hipparcos data. I list the HIP number, the average H_p-magnitude, the frequencies f_1, f_2 (in c/d) and their amplitudes A_1, A_2 (in mag) for a biperiodic fit, the fraction of the variance explained by such a fit (the fraction of observations explained by a fit from f_1 alone) and the reduction of the standard deviation (in mag). The stars in italic are those from the list by Balona (1995), while the others are from the list by Hubert & Floquet (1998)

Star	$< H_p >$	f_1	A_1	f_2	A_2	frac. var.	Δ s.d.
HIP 25007	6.01	1.8522	0.0320	1.0450	0.0179	60%(43%)	0.013
HIP 34981	5.36	0.1611	0.0200	0.3065	0.0105	58%(43%)	0.013
HIP 49934	5.72	0.4323	0.0338	0.5415	0.0285	64%(42%)	0.015
HIP 63688	5.94	0.2533	0.0296	1.1263	0.0190	61%(41%)	0.012
HIP 67472	3.39	0.5621	0.0218	0.1094	0.0154	72%(49%)	0.010
HIP 76013	5.36	0.5849	0.0274	0.2490	0.0244	60%(39%)	0.012
HIP 82868	6.31	1.3349	0.0288	2.1589	0.0178	70%(47%)	0.012
HIP 84650	6.40	1.2854	0.0206	1.2065	0.0149	67%(47%)	0.010
HIP 85467	6.64	0.9058	0.0217	1.9562	0.0121	58%(43%)	0.008
HIP 89977	6.13	2.1045	0.0178	2.4619	0.0150	64%(42%)	0.009
HIP 105091	6.48	0.3141	0.0153	0.2488	0.0140	66%(41%)	0.007

I list the frequencies and their corresponding amplitude for the biperiodic λ Eri stars in Table 2. I conclude that there are indications of multiperiodicity in the Hipparcos data for 11 out of 50 targets. I stress that these findings should be confirmed by means of ground-based photometry and high-resolution

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spectroscopy. In particular, the uniqueness of the biperiodic solutions can be questioned and should be re-investigated once new data are available.

3. Spectroscopic surveys

Systematic high-resolution spectroscopic surveys of λ Eri stars suited to study (multi)periodicity are not at hand. Several initiatives to perform dedicated campaigns on some selected targets have started in the past couple of years. Peters (these proceedings) presents the results of campaigns with IUE. Evidence of pulsation cannot be found for any of the stars from these IUE datasets.

A promising initiative that could induce progress in the field of multimode detections in λ Eri stars are the MU(lti)SI(te)CO(ntinuous)S(pectroscopy) runs recently undertaken by the MUSICOS-team. They have dedicated a 3-day MUSICOS run to study the line-profile variations of the λ Eri star 48 Per (Hubert et al. 1997). Unfortunately, the run resulted in only a very low frequency resolution and the authors were not able to make conclusions about the frequency spectrum, let alone perform modelling of the observed variations. I refer to Henrichs (these proceedings) for further results of the team.

A more systematic spectroscopic study dedicated to several bright λ Eri stars was performed by the Heidelberg group with the HEROS instrumentation (Stefl, Rivinius et al., these proceedings). The active λ Eri star μ Cen was the first star that was studied in detail from HEROS data, supplemented with earlier CAT/CES and 1.52m/Boller-Chivens spectra by Rivinius et al. (1998). These authors were able to detect 6 frequencies in the line-profile variations of this star. Four of the periods seem to form a multiplet centered around 0.5 d while the two others are close periods around 0.28 d. The authors interpret the 6 periods in terms of non-radial pulsation modes and find that the Hα emission phases, and thus the mass-loss episodes, of μ Cen seem to be induced by the beating of the non-radial modes. Direct confrontation of the observed spectra with theoretical spectra based on the derived multiperiodic non-radial pulsation model is presented in a poster at this conference. The star μ Cen is the only multiperiodic λ Eri star so far for which detailed modelling, based on a large high-quality spectroscopic data set, has been performed. New results for 28 CMa and 28 Cyg based on HEROS data are presented by Mainz et al. and by Rivinius et al. (these proceedings).

4. Overview of claimed multiperiodicity

In Table 3, I give an overview of the claims for multiperiodicity that appear in the literature. I list 13 stars for which we found such a claim. Their spectral type, rotational velocity, and derived periods are given, together with some information on the data and the most recent reference of the paper. In the last column I have given a personal opinion about the firm presence of multiperiodicity. *"Yes"* means that I believe in the reality of multimodes, while *"no"* either means that the authors themselves concluded that multiperiodicity is not yet unambiguously established or that I believe that multiperiodicity cannot be derived with the amount of observational material presented in the paper(s). It is to be stressed that I did not perform any analyses on the data, but that my

Table 3. Overview of claimed multiperiodicity in the literature

Star	SpT	vsini	periods	remarks	reference	opinion
ζ Oph	O 9.5 V e	450	0.084 d, 0.139 d & others	P_{super}=0.419 d	Kambe et al. '97	yes
η Cen	B 1.5 V ne	350	0.6424 d	cycle-to-cycle variations of stochastic nature	Stefl et al. '95	no
λ Eri	B 2 IV ne	240	0.708 d, 0.354 d or aliases	spectra 5 years	Kambe et al. '93	no
μ Cen	B 2 IV-V e	130	$P_1 \rightarrow P_6$ 1.06 d	long-term spectroscopy photometry	Rivinius et al. '98 Dachs & Lemmer '91	yes
28 Cygni	B 2.5 V e	310	0.65 d, 0.135 d 0.65 d, 0.76 d 0.74 d, 0.37 d	spectra photometry 110 spectra over 7 nights quasi-periodic or stable periods ?	Peters & Penrod '88 Pavlovski & Ruzic '90 Bossi et al. '93	no
ω CMa	B 2-3 IV-V e	100	1.365 d	transient period of 1.45 d medium term trends removed	Stefl et al. '99	no
48 Per	B 3 V e	217	0.17 d 1.18 d? 0.36 d ?	MUSICOS, 3 days	Hubert et al. '97	no
48 Lib	B 3-4 V e	395	0.54 d, 0.32 d, 0.09 d 0.402 d	51 spectra, 4 nights photometry	Floquet et al. '96 Cuypers et al. '89	no
EW Lac	B 4 III e	350	0.36 d, 0.63 d, 0.8 d 2.22 d	low freq. res. (7days) only in spectra	Floquet et al. '92	yes
KY And	B 4 V e	?	0.751 d or 1.504 d	50 data points, 16 nights additional frequencies ?	Pavlovski & Ruzic '88	no
LQ And	B 4 V ne	280	0.31 d or 0.62 d	 7.413 d=P_{orb} & 0.62 d=P_{rot}	Sareyan et al. '88 Matthews et al. '91	no
θ CrB	B 6 V e	320	0.87 d, 0.46 d	P=10 d prewhitened no period in spectra	Guerrero et al. '92	no
o And	B 6 III pe	230	1.587 d, 0.794 d	variable amplitude ?	Sareyan et al. '98	no

opinion simply originated by critically reading the papers.

I are convinced about the reality of the multiperiodicity for only 3 stars presented so far in the literature. For most studies, indications of multimodes are given but additional data are necessary to firmly establish this detection. Multiperiodicity is additionally claimed for several stars in poster papers presented at this meeting. I refer to the papers in these proceedings for the results.

5. Conclusions on multimode detections

I conclude that very few studies have given firm evidence of the presence of multiperiodicity in the λ Eri stars. Spectroscopic and photometric data sets often reveal different periods. The latter is also the case for some β Cep stars (e.g. β Cru, Aerts et al. 1998), some SPBs (e.g. HD215573, Aerts et al. 1999) and also for the line-profile variable ε Per (De Cat et al., in preparation). This shows that photometric studies are often insufficient to study the temporal behaviour of the λ Eri stars. I have provided a list of 11 λ Eri stars that are good candidates for the presence of multiperiodicity.

I emphasize that long-term dedicated campaigns are necessary in order to make definite conclusions about the periods in selected λ Eri stars. Herein I have concentrated on both monoperiodic and candidate-multiperiodic stars. I also stress that detailed modelling, after an unambiguous frequency determination has been achieved, is an "absolute must" to interpret the data in a correct way.

6. A Case study: the λ Eri star HD 105382

The star HD 105382 was classified as a Be star by Hiltner et al. (1969), who found clear emission in the Balmer lines. On the other hand, Dachs et al. (1981) took spectrograms in 1978 and conclude that the star should be deleted from all Be catalogues. Balona et al. (1992) find a clear period of 1.2927 d in photometry. It is suggested that the star could be an interacting binary, although the available RV data do not support this view. The Hipparcos data reveal the period 1.295 d, which leads to a nice phase diagram. After prewhitening, I do not find another frequency.

I have selected HD 105382 along with 17 southern SPBs for long-term spectroscopic and photometric monitoring with the aim to unravel the cause of its variability. The star shows photometric and line-profile variations that are at first sight not markedly different from those of SPBs. In fact, I would have classified the star as an SPB from our first data if it were not for the fact that it was known as a λ Eri star. In this respect it is an ideal case to compare with the SPBs. Since different opinions about its Be character are present in the literature, I have taken a high-resolution Hα spectrum in May 1996, which clearly shows double-peaked emission with a maximum of 7.5 continuum units. I concluded from then on that the star is a very active λ Eri star and deserves further attention.

I have taken 132 photometric observations during several 3-week missions with the Geneva telescope in 1997. The 105 spectra were taken with the CAT/CES during 10 weeks of monitoring spread over 1996 – 1998. I refer to Briquet et al. (in preparation) for a detailed description of the data, but

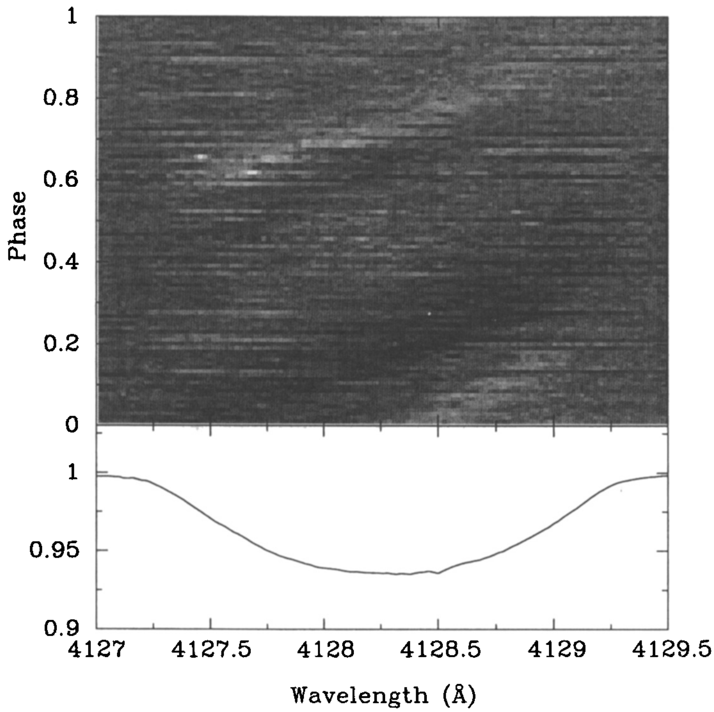

Figure 3. The 105 residual spectra with respect to the average line profile of the Si II 4128Å line (lower panel) are represented as a function of the phase (calculated for the period 1.295 d) in a grey-scale picture. Black denotes local absorption while white represents local emission

mention here that both data sets clearly reveal the Hipparcos period again. After prewhitening, no periodicity remains in the residuals. Thus, we are dealing with a monoperiodic star. The spectra for HD105382 are shown in a grey-scale plot in Fig. 3. They are phased according to the frequency 0.7721 c/d. It can be noted that a subfeature is traversing the profile from blue to red during the first part of the cycle. The motion during the second part is less clear.

At present we are still working on the detailed modelling of the data (Briquet et al., in preparation), but the main thing I want to emphasize here is that this star is a monoperiodic, and at the same time, a very active λ Eri star. In this case, a scenario that relies on multifrequency beating, of whatever origin, is not applicable to explain the emission and mass-loss activity.

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7. Some reflections

The idea that multiperiodic non-radial pulsations could cause the mass-loss in Be stars was put forward by Dietrich Baade from observations of line-profile variations in two seemingly very similar λ Eri stars as regards spectral type, vsini and variability: 28 CMa and μ Cen (Baade 1982, 1984). Now, 15 years later, these two stars are the only ones so far for which detailed modelling of the line-profile variations has been performed. Rivinius et al. (these proceedings) modelled the variations of μ Cen in terms of two of the six detected modes. It is a pity that they did not take into account the four other modes because this might have better explained the small asymmetry observed in the spectral lines. For 28 CMa, modelling in terms of a pulsational (Mainz et al., these proceedings) and a patch model (Balona et al. 1999) is presented. 28 CMa shows only one stable period, besides the occurrence of transient periodicity (Stefl et al., these proceedings). Detailed modelling of observed line-profile variations of other λ Eri stars is currently not yet available. Large efforts to achieve this for two other stars, ζ Oph and λ Eri, were recently made by Kambe et al. (1993, 1997 & these proceedings).

In my opinion, the only strategy to solve the question on the relevance of non-radial pulsations for the Be phenomenon is to gather long-term photometric and spectroscopic data for a large sample of Be stars, preferably with the same instrumentation. The sample should be unbiased with respect to spectral type, vsini, and periodicity. To assume that multimode beating in terms of non-radial pulsations is a good explanation for the mass-loss of Be stars is premature. At present, the number of Be stars for which accurate modelling is available is by far too small to make any useful conclusion in this direction.

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Discussion

P. Harmanec: I appreciate your fair and critical approach. I think it is fair, however, to warn that although the Hipparcos photometry is very accurate and represents a unique invaluable data base, it is not particularly suitable to search for multiperiodicity. It is true that less 1-c/d aliases are present, but the window function usually still contains a dense forest of peaks.

C. Aerts: First of all, the SOC specifically asked me to look for multiperiodicity in the Hipparcos data. You are absolutely right in warning that a correct interpretation of the often very complicated periodograms is dangereous. In this sense, I have indicated 11 stars as candidate multiperiodic objects, but would like to stress again that this finding has to be confirmed by follow-up data. On the other hand, the Hipparcos data have shown to contain very useful information for SPBs and we were able to confirm the multiple frequencies found in the Hipparcos data for most of the bright SPBs for which we obtained ground-based photometric and spectroscopic follow-up data.

D. Baade: What fraction of the data sets examined by you have a sufficient time sampling to search for two or more periods spaced by about 1%?

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C. Aerts: Frequency multiplets can be found from the Hipparcos data, e.g. the well-known triplet for the β Cep star ν Eri can be recovered, but this is a star for which a multiplet structure was already known from older ground-based data. I doubt that we would have recovered the triplet without prior knowledge of the excited frequencies.

As for our ground-based follow-up photometry and spectroscopy: the total time base of the spectroscopic data amounts to 2 years and the data are each time taken during a week. One would expect to have an accuracy of at least 0.001 c/d so it should be possible to find close frequency multiplets if they were excited.

A.M. Hubert: You contest the use of a large amplitude in rapid variability as a criterion of multiperiodicity. I used it because intensive ground-based photometric surveys have shown the same phenomenon in Be stars such as EW Lac, 28 Cyg, o And, which turn out to be multiperiodic variables. The large amplitude is interpreted as a beat phenomenon of several modes.

C. Aerts: I simply extended your criterion in the sense that I did not want to limit myself to large-amplitude variables in my search for multiperiodicity. Some well-known multiperiodic stars have very small photometric amplitudes. This can be due to negative interference, or to the presence of higher-degree modes. By taking into account all periodic variables, both with a small and a large amplitude, I considered a sample as large as possible to search for multiperiodicity.

R. Townsend: (i) The asymmetry in the line profiles of μ Cen that you point out can be attributed to wave-leakage. (ii) What is wrong with the modelling of 28 CMa by Mainz et al.?

C. Aerts: (i) Your suggestion that wave-leakage could cause the asymmetry found in the line profiles of μ Cen is very interesting and I encourage you to try and model the observations with your code that takes this phenomenon into account. (ii) The theory used to model the line-profile variations of 28 CMa is only accurate in the case that the centrifugal forces can be neglected. For the solution for 28 CMa, the authors have taken a ratio of the rotation to pulsation frequency of almost one. This, in combination with a velocity very close to break-up, is pushing the theory beyond its region of applicability. Therefore I advise care in interpreting such modelling.

S. Stefl: I would like to remark that the Hipparcos data of 28 CMa do not reveal the variability which is clearly present in long-term ground-basd photometry due to poor time sampling. In this respect your derived percentage of multiperiodic stars is a lower limit.