YU ISSN 0351-2651
HOBUD7 7(1) 29(1983)

THE PHOTOMETRIC VARIABILITY OF B STARS : A GENERAL APPROACH

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UDC 524.312.7-56
review

Introduction

Many review papers have been published in recent years concerning the observational facts on the variability of early-type stars, the most recent and most complete being the paper by Cox (1983). Quite often, however, these review papers bring together the data from various sources, the homogeneity of which is sometimes open to question. The danger of such an approach is that spurious results may persist in the literature and that selection effects may occur, problems that are discussed at length in many of the mentioned review papers.

An instructive example is given by the "ultra-short-period variable stars". This class was defined by Jakate (1979b) on the basis of the photometric variations he observed in four stars. In subsequent years, the existence of this class was accepted and mentioned in many review papers. More recent observations (Balona, 1982; Waelkens and Rufener, 1983d; Shaw et al., 1983), however, could not confirm the variations cited by Jakate. In fact, we found that HR 3467, "the best-studied case" according to the original paper, was variable, but on a time scale quite different from the one proposed!

Therefore we felt that instead of presenting one more standard review paper, it would be more useful to work out an approach that avoided these difficulties as much as possible. To do this, it is necessary

- to work in a photometric system in which homogeneous measurements can be made for a large sample of stars;
- to choose a sample of program stars in as unbiased a manner as possible. Some of the selection effects that should be avoided are these:

(1) Most early variable stars were first detected spectroscopically. The definition of this class of variables is thus biased by spectroscopic criteria, since other stars could show the same kind of photometric variations (e.g. the distinction between "Be-variables" and "broad-lined variables").
(2) Even when the observed phenomena are clearly different, some relations between the different classes could exist and could remain undetected when all classes are treated separately.
(3) Most observers look for variability on short time scales, for both theoretical (the search for pulsations) and practical reasons (telescope time distribution). This selection effect is well illustrated by the "ultra-short-period variable stars". Also, for some stars (e.g. some Be stars), it is known that different time scales are involved for the variability of the same object, but little things are known about the interactions between these different types of behaviour.

1. The Methods

In this paper, we report the results of the new observations of variable B-stars that were performed using the Geneva Photometric System. For most objects, these observations were performed with the Geneva Photometer attached at the Swiss Telescope at La Silla Observatory, Chile, from 1980 through 1983. In addition, some northern program stars were observed at Jungfraujoch, Switzerland, from 1979 through 1982, with similar equipment. In this section, we will justify our choice of experimental methods.

Characterization of B-stars in the Geneva Photometric System:

The Geneva System has been reviewed in detail by Golay (1980). In all photometric calibrations the five intermediate bands U, B1, B2, V1, and G are used, while the broad bands B and V are similar to the Johnson B and V bands. For the early type stars, it is practical to use reddening-free parameters only. One defines

$$\begin{aligned} d &= (U-B1) - 1.430(B1-B2) \\ \Delta &= (U-B2) - 0.832(B2-G) \\ g &= (B1-B2) - 1.357(V1-G). \end{aligned} \qquad (1)$$

The physical interpretation of these parameters is not easy. However, Cramer and Maeder (1979) noted that the O - A2 stars lie essentially on a plane surface in the three-dimensional space d - Δ - g. They then determined the main axes of the configuration and so defined new coordinates X, Y and Z. It turned out that
- X = X(U-aB1-bB2), for some positive a and b, so X is a temperature index,
- Y = Y(B1-B2), so Y is a luminosity index, since B1-B2 is a measure of the width of the hydrogen lines H δ, H ε and H ζ,
- Z = Z(V1-G), so Z is sensitive to the λ5200 A - feature of the CP-stars. In fact, it turns out that only the magnetic CP-stars do deviate significantly from the XY-plane (Cramer and Maeder, 1980).

The parameters X and Y have been calibrated in terms of effective temperature and absolute magnitude, while Z was found to be an indicator of the mean surface magnetic field (Cramer and Maeder, 1979, 1980). In this paper, we will not use these calibrations, and only work with observational parameters.

Precision of the data:

The last Geneva Catalogue (Rufener, 1981) is based on more than 70000 measurements of 14633 stars, made in the course of 20 years. The mean precision of the catalogue has been discussed by Rufener (1981) and by Rufener and Bartholdi (1982). It was found that the precision is best for the stars with apparent visual magnitude between 3 and 10, i.e. the range of the stars discussed in this paper. A χ^2-fit to the data of all stars with three or more measurements gave a typical standard deviation of 0.0082 mag.

The observational errors in this range are mainly of two types:
- those due to instrumental instability and irreproducibility. The typical scatter for the stars which were measured over 20 years, with up to seven different instruments amounts to about 0.009 mag; for three years, i.e. the duration of of our observation campaign, it is of the order of 0.006 mag.
- residual and unaccounted for extinction variations. The accuracy of the determination of the extinction parameters depends largely on the frequency of the standard star measurements. For the usual Geneva programs, two standard stars are measured each hour, since the resulting precision is considered to be sufficient for most purposes. For our specific program, we adapted the frequency of the standard stars to the required accuracy and the external conditions. In this way, an internal precision of 0.002 mag was possible for some nights.

2. The Sample of Program Stars

(a) Definition of Criteria for Microvariability:

Their statistical investigation of the data in the catalogue allowed Rufener and Bartholdi to define microvariability criteria by considering the tail of the distribution of the standard deviations. Based on these criteria, they published a list of 333 new "microvariable, probably microvariable and possibly microvariable" objects that were not listed in the General Catalogue of Variable Stars (Kukarkin et al., 1969) or its three supplements.

For our purposes, it is interesting to note that 32% of the stars of this list are B stars. We examined as many objects as possible from this list, since, in our view, it constitutes a sample which is relatively free from observational bias. This last statement is only true to the degree that the stars in the catalogue were not selected with the purpose of studying stellar variability. This is the case for most stars (the Bright Star Catalogue constitutes the bulk of the sample), but is violated for the supergiants, for which there has been considerable interest for many years in the Geneva System. In addition, it is obvious that these microvariability criteria tend to select the large amplitude variables. Still, in the case of the Beta Cephei stars, which mostly have small amplitudes, the criteria would have discovered some larger amplitude variables (such as KP Per, Nu Eri, HD 80383, and BW Vul), and so the phenomenon would not have remained undetected.

(b) Distribution of the Scatter in The XY-Diagram:

The second approach, again based on the sample of B-stars measured in Rufener's 1981 catalogue, starts from the distribution of the standard deviation of the V-magnitudes as a function of the position of the stars in our observational HR diagram. This approach is similar to that of Maeder and Rufener (1972), which was used on a smaller sample, and to that of Maeder (1981). These authors have shown that the O- and earliest B-stars and the B-supergiants are considerably more variable than the mean of the B-star population.

We repeated this analysis after exclusion of the Be-stars, for which the physical interpretation of the colours is less certain, for the approximately 1500 B-stars for which three or more good measurements are available. We then divided the XY-diagram into "boxes" with dimensions 0.10 in X and 0.01 in Y (these dimensions are an optimization between the statistical significance of the subsamples and the physical meaning of the boxes), and computed the mean scatter for each box. Figure 1 gives the results: the crosshatched boxes have $\sigma_v \geq 0.012$, the lined boxes have $0.008 < \sigma_v < 0.012$, and the dotted boxes $\sigma_v \leq .008$. When a box contained less than three stars, it was not included on the figure. This last procedure eliminates the most luminous stars in particular.

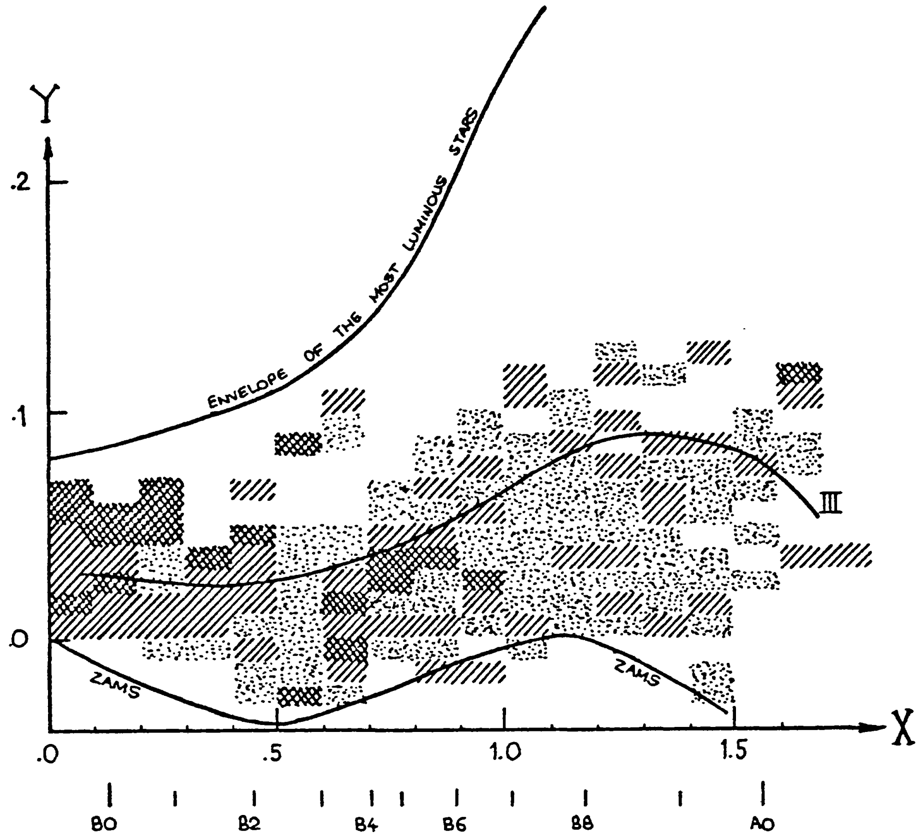


Fig. 1 : The distribution of the scatter on the mv - data, as a function of the location in the XY - diagram (see text).

Of course, the previous results are confirmed. In addition, two suggestions can be made:

- No new conspicuous phenomena are observed for the late B-stars (later than B7). In fact, practically all such stars in our sample with large scatter are Bp-stars or eclipsing binaries. In particular, the picture of a continuous zone of variability from the Beta Cephei stars to the Delta Scuti stars passing through the "Maia sequence" is not confirmed.
- There appears to be a previously unrecognized zone of larger variability around spectral types B3-7,III-V. The boxes in this spectral region all contain usually some twenty stars, so the phenomenon could be significant. To check this point, we put several of these stars on our program.

(c) The Vicinity of The Beta Cephei Stars

Finally, we tested the variability of all stars we could observe in the region of the XY-diagram around the Beta Cephei stars. It is clear that this part of the project is not completely free from the selection criteria often mentioned with respect to these variables. If the Beta Cephei phenomenon occurs in a broader part of the HR diagram than generally accepted, we implicitly accept that this part forms a connected subset of the XY-diagram; in other words, some of the stars of our sample that are slightly outside the classical strip (up to 0.05 mag in X and 0.01 mag in Y) must then also be variable.

3. Results and Discussion

The initial inspection of Rufener and Bartholdi's list reveals that most of the microvariable B-stars it contains are supergiants or Be-stars. This is not surprising, as the sample is composed of stars not noted in Kukarkin's Catalogue and its Supplements (last compilation: 1976), and interest in the photometric variability of these types of objects is fairly recent. Also, the large amount of variable supergiants in the list reflects the particular interest of the Geneva group for these stars.

In this section, we will describe our photometric results for the different classes of variables separately. The distinction we make between these classes is based on photometric criteria alone and not on a pre-existing spectroscopic definition. To explain this point, when necessary, we will refer to the characterization of the different classes.

(a) Variable Be-Stars

The Be-stars were not considered in the statistical analysis presented in the previous section because the variations of the colour indices for many Be-stars are larger than the size of the boxes in Figure 1. In this subsection, we perform a similar kind of statistical analysis for Be-stars. Most of the light curves we obtained will be presented in a separate paper; here we discuss the general picture and illustrate it with individual cases.

As pointed out in the first section, the luminosity parameter Y is mainly sensitive to the equivalent width of the Balmer lines $H\delta$, $H\epsilon$, and $H\zeta$. The interpretation of this index is then similar to that of the β - index. In fact, an excellent fit of β over X and Y is given by

$$\beta = 2.568 + 0.190 X - 0.487 Y, \quad (2)$$

with a standard deviation of only 0.008 mag for non-emission line stars (Cramer and Maeder, 1979). However, due to the different sensitivity of the Balmer lines to emission phenomena, the β -indices for Be-stars deviate considerably form the values of the index β_c, as estimated with with expression (2). In the context of this paper, we define a "photometric Be-star" to be a star for which $\beta - \beta_c \leq -0.025$, i.e. with more than three standard deviations of expression (2).

Of course, this definition has only a statistical significance. Moreover, for the strongest Be-stars the Balmer discontinuity and the continuum are also affected, so that β_c is no longer a good estimate of the β - index of the underlying star. For these objects, however, the spectroscopic detection of the Be phenomenon is simple. The advantage of our approach is that it allows the detection of emission in some weak-emission line stars. For example, in the case of HD 45871 (HR 2364), we find that $\beta - \beta_c = -0.064$, which is a highly significant value. This star is the prototype of the so-called "broad-lined variables" (Jerzykiewicz and Sterken, 1981; Percy, 1982), which, on the basis of this result,we do not consider to be a class of variables independent of the Be stars.

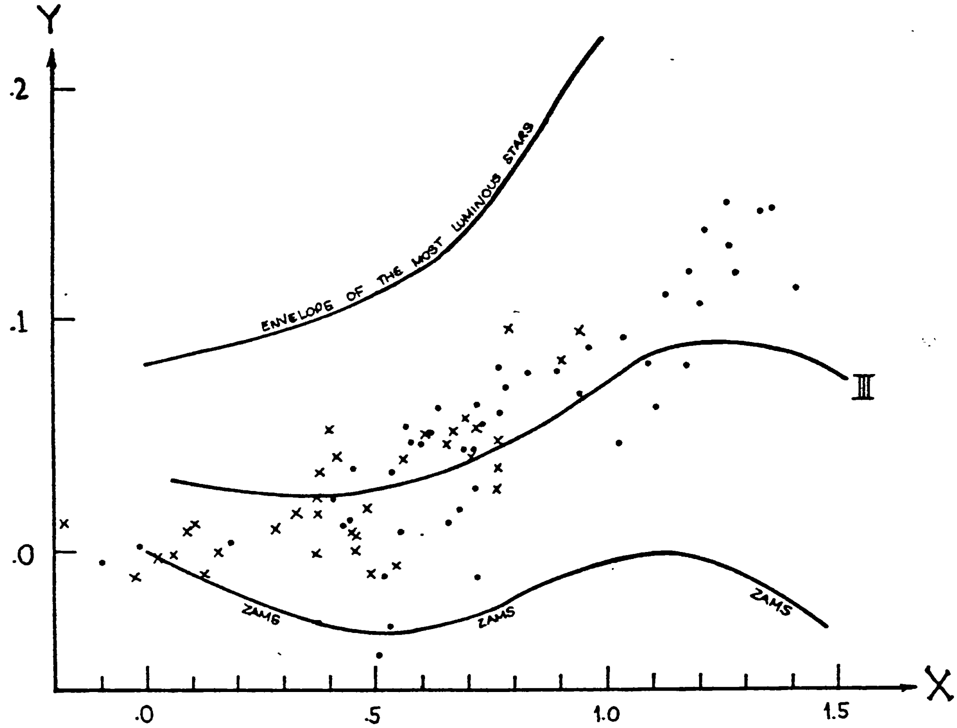


Fig. 2 : The Be-stars in the XY-diagram.

Figure 2 shows the XY-diagram for all southern the B-stars that are common to Rufener's catalogue and the Gronbech and Olsen (1977) compilation of β - indices and that have $\beta - \beta_c \leq -0.025$. The dots represent stars with $\sigma_v < 0.012$, and the crosses stars with $\sigma_v \geq 0.012$. From the figure, two points can be noted:

- The later Be stars all are evolved, while the phenomenon occurs for all luminosity classes among the earlier Be-stars. Nevertheless, most Be-stars stars are giants.

- Relatively more crosses are observed among the earlier spectral types. This does not necessarily imply that the later Be-stars are not variable, but more probably does imply that the earlier Be-stars are more variable on the time scales involved here (up to a few years). For example, a star like Pleione could be considered constant in brightness on the basis of the observations of a few years, but it is well known that it shows dramatic variations from time to time. Another example is HD 93563 (HR 4221, B8-9IIIe), which is on Rufener and Bartholdi's list. It showed no variations in 1983 (σ_V = 0.006), but was then about 0.1 mag fainter than the mean of the previous measurements. On the other hand, for practically all the early Be-stars frequently measured in our program, photometric variability was definitely observed during our three-year observation program.

Because of this last reason, we paid more attention to the early Be-stars. Obviously, we cannot say very much about their long-term behaviour. In only one case do we have a good coverage over a longer time: HD 49336 (HR 2510; B4Ve) was observed quite often (up to 50 points a year) for 7 years. Figure 3 shows the 1977-1983 variations. Each point on the figure is the mean of one half of the data from one observing season. Apparently, the star passed through a minimum that lasted about two years, which also corresponded to the redder U-B and B-V. This behaviour is reminescent of the "type 1" long-term variability in the classification by Harmanec (1983), and we interpret it as caused by a dust cloud. In addition, our 1983 data of HD 49336 revealed small amplitude short-term variations, similar to those observed by Jerzykiewicz and Sterken for HD 45871.

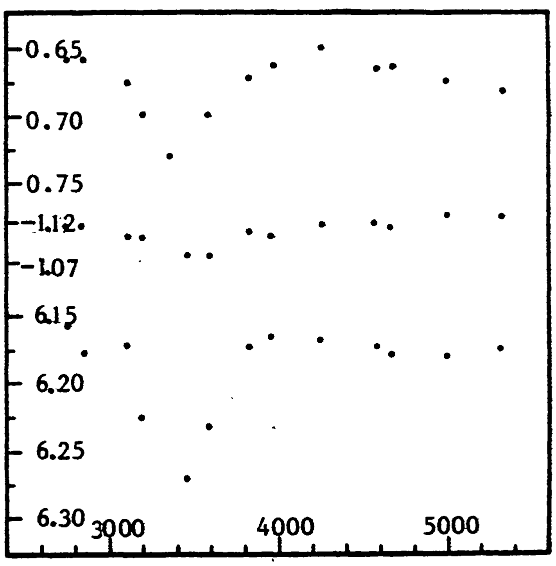


Fig. 3 : Long-term photometric variations of the Be-star HD 49336. The units of the abscissa are Julian Days. The zero-point is at JD 2440000. Given are the variations of the Geneva U-B - and B-V - indices and of the visual magnitude

In our survey, we found three stars for which the essential variations evidently occurred on a short time scale, i.e. less than the rotation period. HD 77320 and HD 157042 will be discussed in a separate paper; HD 35165 (HR 1772; B5IVnpe) generally varied with a peak-to-peak amplitude of 0.02 to 0.05 mag, but once a fading with as much as 0.13 mag in 0.12 days was observed. A more thorough treatment of all data is in preparation, and will be published later.

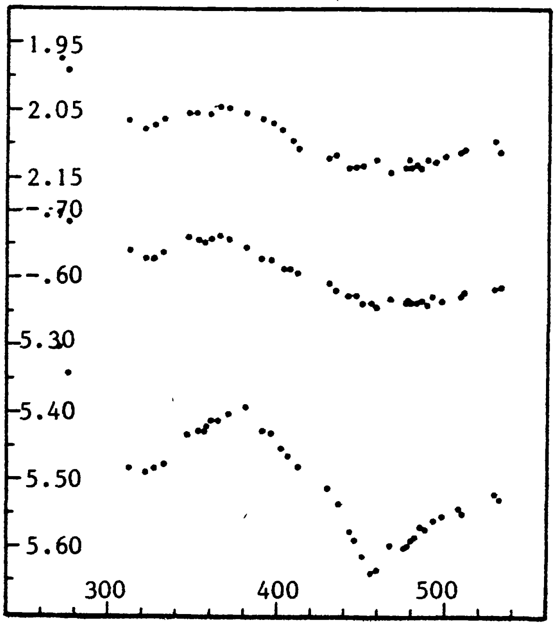
(b) Variable Supergiants

The list of microvariable stars contains 40 B-type supergiants, 12% of all stars in it. A general survey of supergiant variability and specific studies of individual cases have been an important concern of the Geneva group for several years (p.e. Maeder and Rufener, 1972; Burki, 1978; Burki, Maeder and Rufener, 1978; Rufener, Maeder and Burki, 1978), the results of which have been summarized by Maeder (1980). Some of these results, which could be related to other variables discussed here, are:

- The light curves are irregular, but a characteristic time scale can still be defined for each variable. Moreover, these "semi-periods" suggest a kind of PLC-relation parallel to that of the Cepheids. There are thus strong indications that stellar pulsations are responsible for the observed variability.
- The more luminous the supergiant, the more variable it is.
- A maximum of the amplitudes is also observed around spectral type B2-B5, i.e. in that part of the Herzprung gap close to the Beta Cephei stars (Maeder, 1981).

We have included in our campaign some supergiants whose variability had not been described previously. One very interesting object is HD 89353 (HR 4049). Its light and colour variations during 1982-1983 are given on Figure 4. The peak-to-peak amplitude in the visual is about 0.35 mag; in the U-magnitude, it amounts to 0.65 mag! The "period" derived from these data is near 140 days. In view of its large amplitude and time scale, it appears to be likely that HD 89353 is a very luminous supergiant, which is confirmed by its location in the XY-plane. Howeve?, the published spectral type is B9.5 Ib-II. It would be of interest to determine the spectral characteristics of this star at different phases of the photometric period.

Fig. 4 : The light and colour variations of HD 89353 during 1983. The zero-point of the time scale is at JD 2445000.



(c) The Beta Cephei Stars

The list of microvariable stars contains only one Beta Cephei candidate: HD 129929. The variations of this star are shown on Figure 5 and were discussed in an earlier paper (Waelkens and Rufener, 1983a). Three pulsation periods were found: P1 = 0.154776 days, P2 = 0.143268 days, and P3 = 0.155062 days. In our sample consisting of stars in the vicinity of the Beta Cephei stars, we found one other candidate, η Ori (Waelkens and Rufener, 1983b). Further study of this bright star looks very promising, since it is a component of an eclipsing binary and since it has sometimes been classified as a Be star.

Partly motivated by the behaviour of η Ori, we have also checked other close binaries in the Beta Cephei instability strip for short period pulsations (Waelkens and Rufener, 1982 and 1983b). We found that pulsations with detectable amplitudes do not occur for the closest -- and thus most tidally distorted -- systems; all the binaries among the Beta Cephei stars (including η Ori) are well detached systems without ellipsoidal variations, with possibly α Vir as a limit case. We then also noted that the pulsation amplitudes of the shortest-period Beta Cephei binaries are intrinsically variable, again with α Vir as a dramatic limiting case. From this, it was suggested that the tidal interactions have a damping effect on the Beta Cephei phenomenon.

Our investigations reveal 15 stars that are definitely situated inside the instability strip and that do not appear to vary. Some of them are spectroscopic binaries; others are known velocity variables. A spectroscopic investigation to test whether all these stars could be close binaries is in progress.

In contrast to the small number of new Beta Cephei candidates, our sample of stars close to the Beta Cephei stars contains a large number of Be stars. This is partly a result of the selection effects, and illustrates that the search for Beta Cephei stars in the Bright Star Catalogue may be considered nearly complete, thanks to the recent surveys (Balona, 1977; Jerzykiewicz and Sterken, 1977, 1979; Vander Linden, 1983). In a separate paper, we investigate whether a relation could exist between the Beta Cephei stars and these early Be stars.

A small number of other variables was found, the behaviour of which we were unable to classify with the available data. This does not necessarily imply that the known phenomena of variability (binarity, Be, Bp, or Beta Cephei) are unable to account for the observations, although it is difficult to be certain. What we can say is that no picture emerges that would imply clear evidence for a new type of stellar variability in this region of the HR diagram. In fact, our results do not confirm the physical reality as a homogeneous group, independent from the other variables, of the so-called slow variables (Jakate, 1979a). Indeed, about half of the stars quoted by Jakate are Be stars; for some others, the variability is not confirmed by our data. Still, the variability of some stars is not easily understood in the general picture we present here, and new data, gathered with other techniques are required in order to determine whether their behaviour is genuinely different. We give two examples:

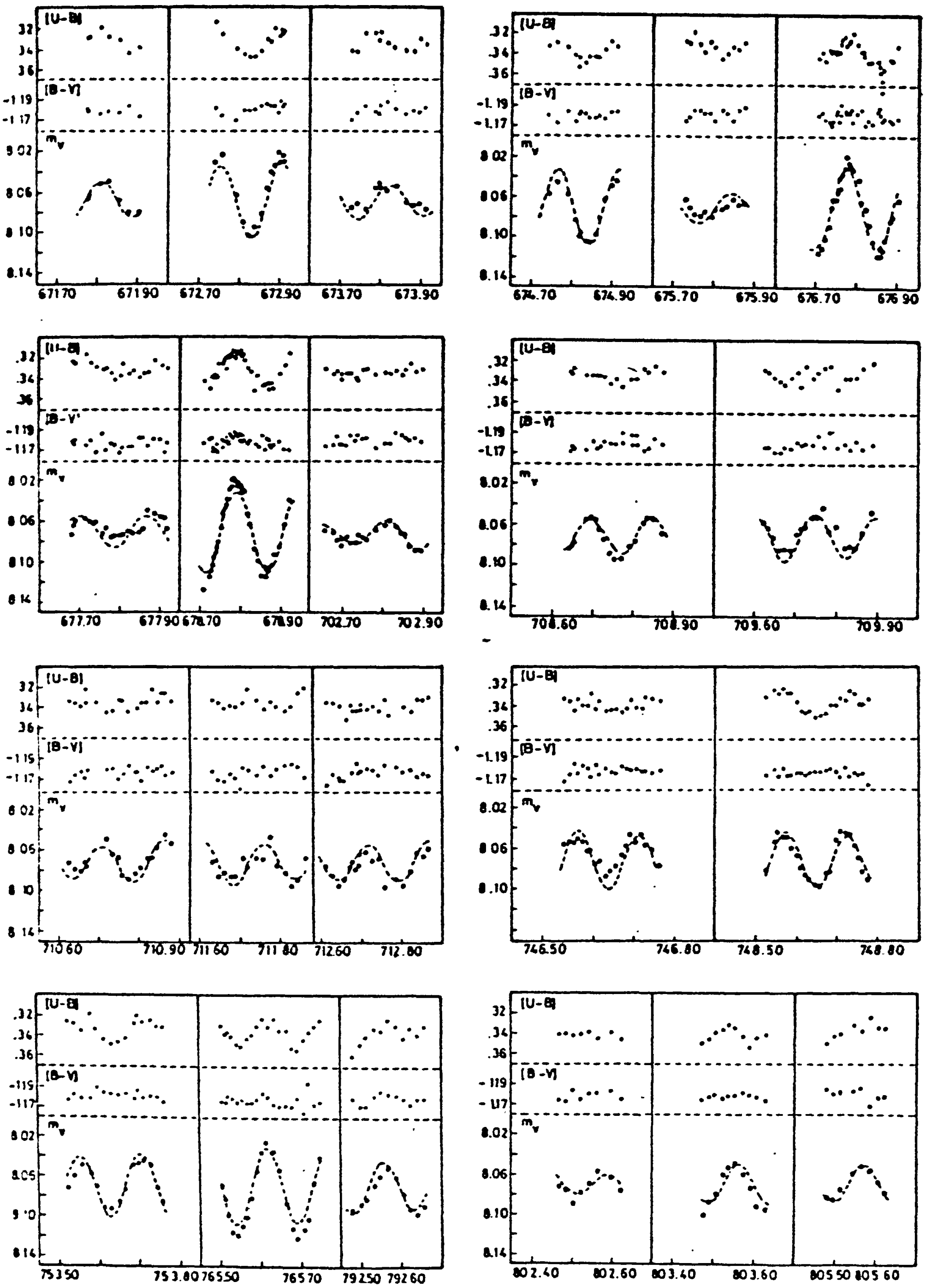


Fig. 5 : The light and colour variations of HD 129929.

- HD 85871 (HR 3920, B1IV) is situated in the center of the instability strip in the XY-diagram. Our 1981 and 1983 data sets both reveal the same significant period of near 1.2 days, but the resulting light-curve is noisy. Our period is probably compatible with the data of Jerzykiewicz and Sterken (1977), since it is a 1 cycle/day alias of the period they proposed as "the shortest possible period" for HD 85871. It is not impossible that the star is a close binary, with ellipsoidal variations and additional light variations due to emission by a circumstellar shell. This interpretation may be consistent with the variable radial velocity noted in the literature and with the difference of the β_c - index with some of the published β - indices (Hauck and Mermilliod, 1980).

- HD 62747 (HR3004, B1.5III) is also a star found to be "slowly" variable by Jerzykiewicz and Sterken and is situated inside the instability strip. In our campaign, the star was constant during all but two nights, when it dropped by 0.03 and 0.06 mag. If Jerzykiewicz and Sterken also observed variability of this star only during a fraction of their campaign, it could mean that the observed fading was due to shallow eclipses.

It is clear that the explanations that we proposed for these stars are not the only possibilities. However, we feel that many more, and different, observations are necessary before one can claim the existence of a new type of stellar variability.

(d) Variable Bp-Stars

There are at least two ways of detecting peculiar B-stars in the Geneva System:

- For the CP2-stars (the magnetic CP-stars), the λ 5200 A feature (Hensberge and Maitzen, this workshop) is detected through the Δ (V1-G)- and Z-indices (North and Cramer, 1981). From this last index, an estimate of the mean surface magnetic field can be made (Cramer and Maeder, 1980).

- For the helium-weak stars, the photometric spectral classification SP(X,Y) is several subclasses earlier than the MK spectral type.

The light variations of the Bp-stars are well described in the literature, and are to be understood in terms of the oblique rotator model. The photometric period is equal to the rotation period of the star. The light and colour variations are explained at least partly by the combined effects of blocking and blanketing associated with the non-homogeneous distribution of the elements over the stellar surface. In addition, there is some evidence that other parameters, such as effective temperature, must also be variable over the stellar surface to explain the light curves of some stars (Stepien, 1980).

Table 1 lists some Bp-stars we monitored at La Silla; the light curves are shown on Figure 6. The observed variations have an exceptionally large amplitude in the case of HD 98457 (0.19 in U-B; 0.13 in mv) and of HD 191287 (0.14 in U-B; 0.20 in mv). Figure 6 is also a useful check of the precision of the data discussed in section 1.

For HD 56455, the data were obtained over three years, with the observation procedure normally used for the general Geneva program, and the scatter around the mean curves is around 0.006 mag. The three other stars were measured for one season with more standard star measurements. The scatter is then about 0.003 - 0.004 mag.

Table 1 : Data for some Bp stars

HD	SP(X,Y)	SP(MK)	Z	P (days)	light range
56455	B7III	A0pSi	-0.009	1.9347	5.69 - 5.74
98457	B7III	A0	-0.022	11.537	7.87 - 8.00
133880	B7III	A0pSi	-0.064	0.8775	5.76 - 5.81
191287	B7 ?	B9	-0.037	1.6235	8.08 - 8.28

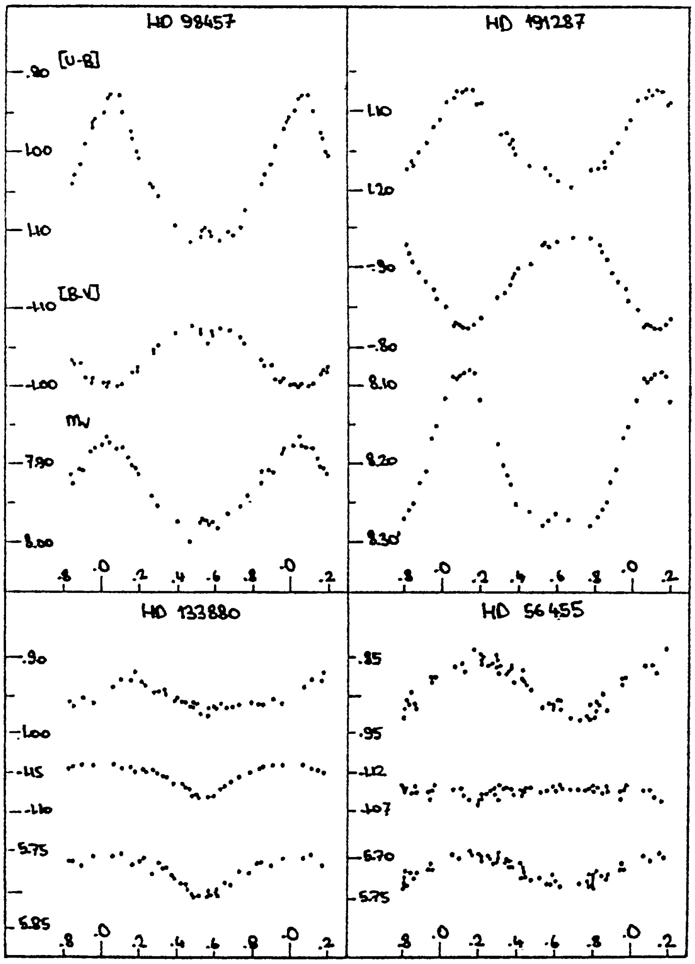


Fig. 6 : Phase diagrams for the Bp-stars listed in the text.

(e) Variable "Mid B" Stars

We now turn to the objects responsible for the larger scatter in mv around spectral types B3-7III-IV (Section 2). We only discuss those cases for which the already reduced data permit some conclusions. The reduction of the data of other similar stars is in progress. None of these stars is known as a Bp- or a Be-star. The comparison of our photometric data with the published information also suggests that any peculiarity or emission, if present, must be small for these objects.

For most of these stars the suspected photometric variability was confirmed by the new data. Moreover, the observed photometric behaviour is similar and can be summarized as follows:

- A significant periodicity is present. The periods found for these stars range between 1 and 3 days. The peak-to-peak amplitudes are in the range 0.04 - 0.10 mag. The phase diagrams are given on the figures 7 to 9.
- The U-B -variations are in phase with the mv-variations; their amplitude is somewhat smaller, but of the same order as that of the visual light curve. The B-V -variations are minor.
- The amplitudes are variable. Indeed, the noise around the mean light curves is partly intrinsic: this can be seen by comparing the light curves of Figures 6 and 7, which have the same scale and the same precision. The colour-to-light ratio is apparently constant.

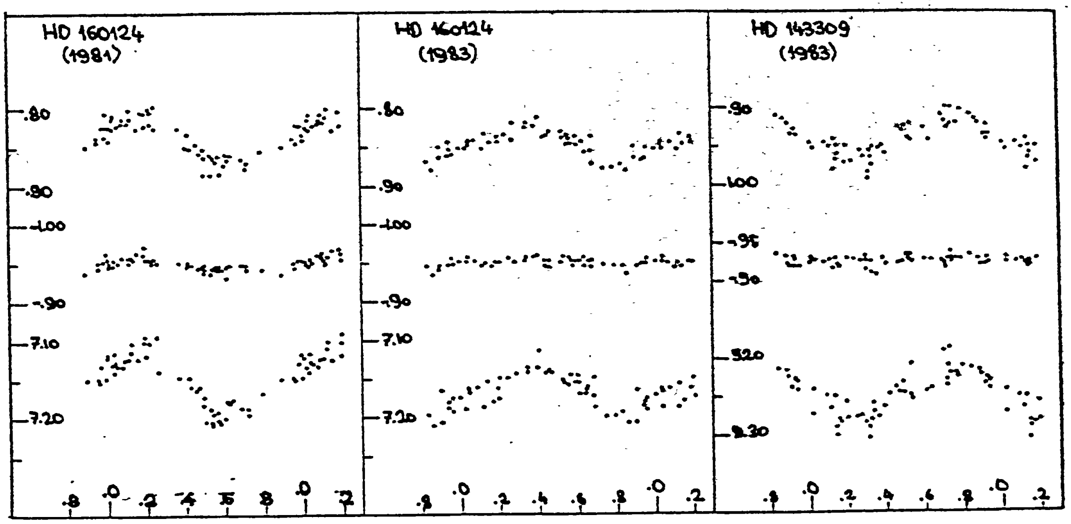


Fig. 7 : Phase diagrams for HD 160124 (1981 and 1983) and HD 143309.

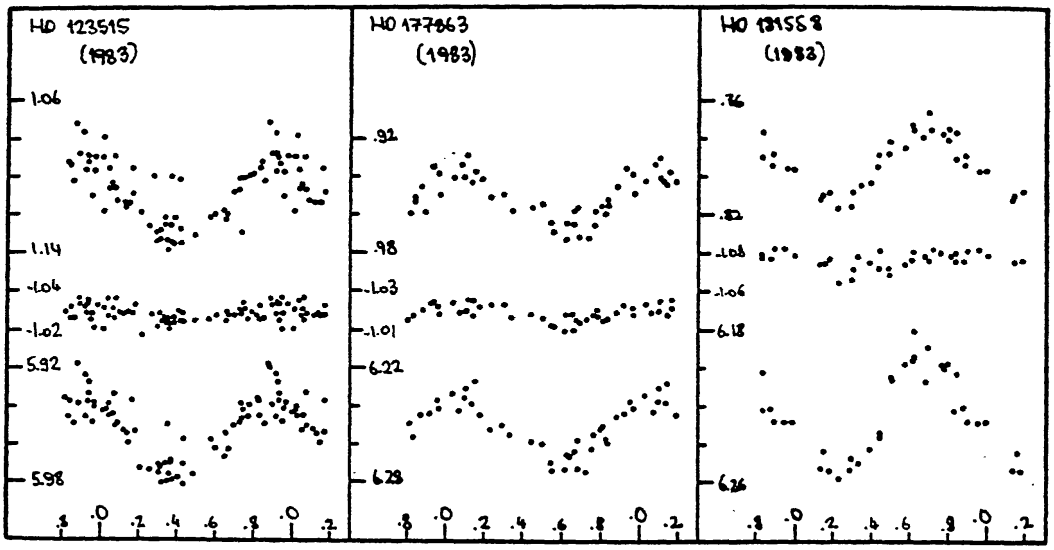


Fig. 8 : Phase diagrams of the 1983 data of HD 123515, HD 177863, and HD 181558.

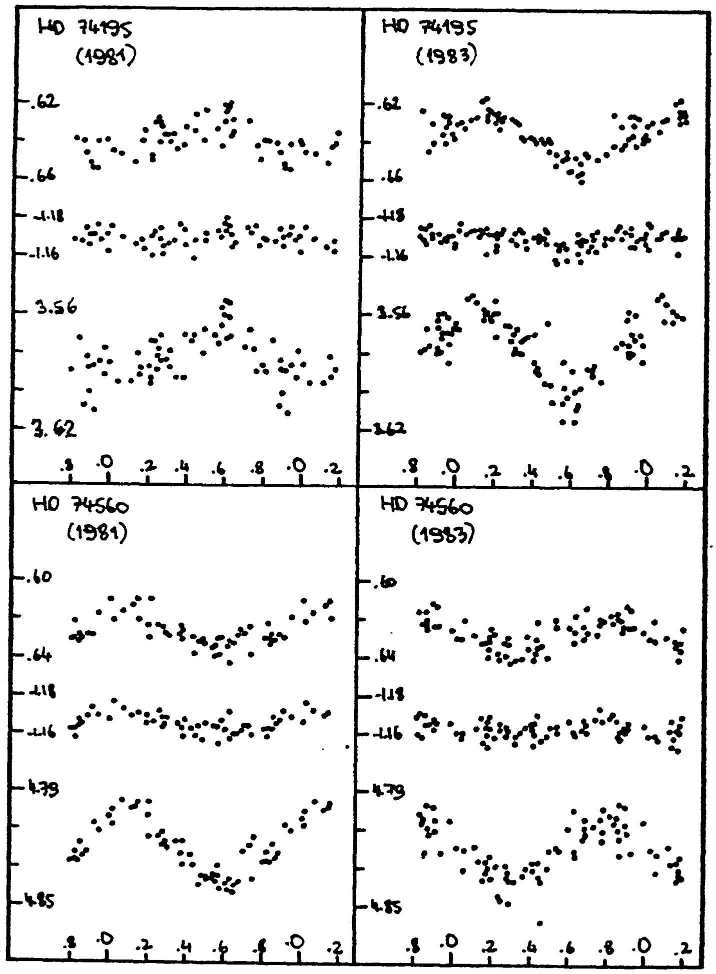


Fig. 9: Phase diagrams of HD 74195 and HD 74560, in 1981 and 1983.

Three stars were measured for two different years: HD 160124 (Fig. 7), HD 74195 and HD 74560 (Fig.9). For all three stars, not only did the data for each year lead to a noisy light curve, but also the mean amplitude, averaged over up to 100 cycles, was not the same. If the amplitude variations are thus intrinsic, one should be extremely careful with the period analysis. Indeed, strictly speaking, the Fourier technique we used is only valid for monoperiodic and multiperiodic variations with intrinsically constant amplitudes. We still are confident that the periodicities are real, since they were recovered for different data sets. However, we feel that an estimate of the precision in the usual way is not possible. In particular, while the differences between the 1981 and the 1983 periods are less than 0.1% for HD 160124 and HD 74560, this difference amounts to about 1% for HD 74195.More observations are needed before it can be determined whether a genuine period variation occurs.

Both HD 74195 and HD 74560 are stars about which there has been some controversy in the literature. This controversy can partly be accounted for by selection effects. Recently HD 74195 (Omikron Velorum) was still claimed to be a "certain β CMa star" (Valtier et al., 1981) on the basis of radial velocity variations, which are better described with our period than with the short period originally proposed (Waelkens and Rufener, 1983d). The case of HD 74560 has already been mentioned in the introduction. For both stars, no thorough search for any variability on a longer time scale was ever performed!

An object probably similar to the stars described here is HD 76566, which was discussed by Burki (1983). The variations observed and described by Burki are shown in Figure 10. They satisfy the characteristics we derived from our data: the time scale is 1.8 days; the U-B -variations are in phase with and of similar amplitude as the light variations; and the mean amplitudes are variable from one year to another. Burki interpreted his data in terms of a multiperiodic phenomenon: a four frequency fit represents the light and colour curves quite nicely.

It is then tempting to search for other periods in our data but we feel that one should be cautious, because of the intrinsic variability of the amplitudes. Any signal with one real period but with variable amplitude can be described as a multiperiodic signal during some short interval in time. In the case of truly multiperiodic pulsating stars, such as the beat Cepheids, the Beta Cephei, or the Delta Scuti stars, it is very rare that the pulsation amplitudes are not constant on a time scale of some years. Nevertheless, the case for Burki's interpretation is strenghtened by his finding of the same periodicities in different data sets.

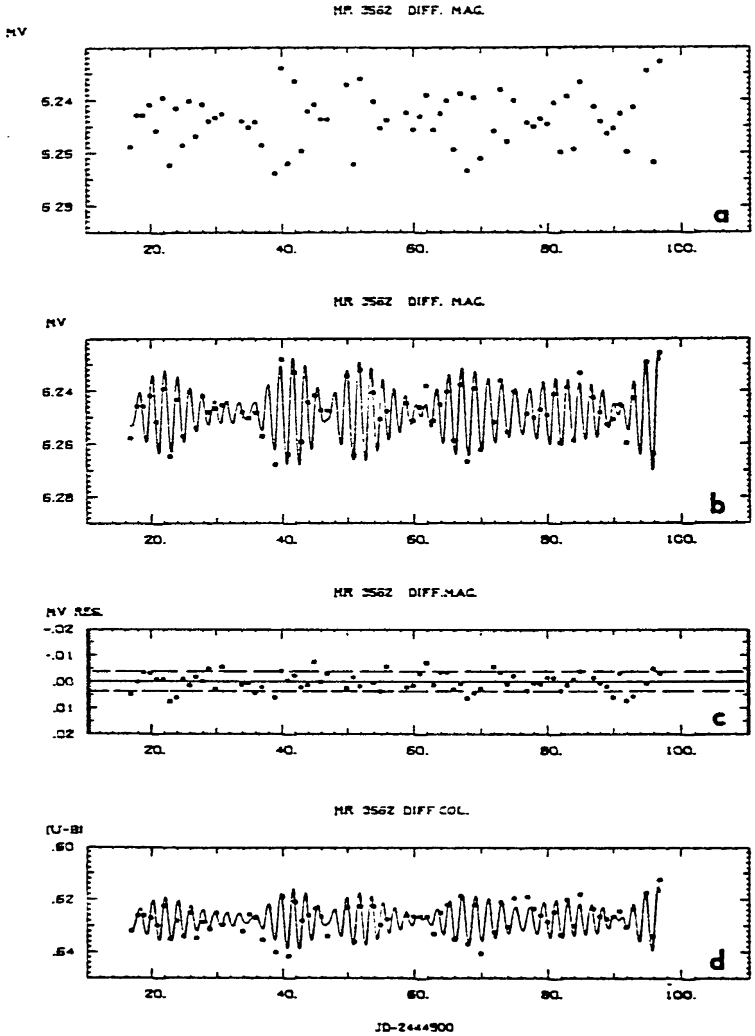


Fig. 10 : The light and colour variations of Burki's star.

We see three possibilities for the physical meaning of a stable periodicity in the light variations observed for these objects: an orbital period, a rotational period, and a pulsation period:

- Although the observed periods are of the right order, the probability of the correctness of a binary interpretation is low. The colour variations are rather high for detached systems; the amplitude variations remain unexplained in this model; and the radial velocity data do not really point into that direction, although some of the stars from Table 2 are "velocity variables". Moreover, HD 123515 is a known SB with an orbital period of 26 days, so an additional component orbiting with P = 1.456 days would not have remained undetected.

- The interpretation of a rotation period is more attractive. The periods are of the right order; they are compatible with the scarce v sin i values available for these stars; the light curves are most similar to those of some Bp stars (Fig. 6). But it then remains to be explained why no or only marginal peculiarity is observed, especially if the photometric variability is thought of in terms of variable blocking and blanketing. Moreover, the amplitude variations and of course the multiperiodicity, if confirmed, are not easily accounted for. It is very interesting to note, however, that a similar "multiperiodic" behaviour has been observed in at least one mild Bp-star, HD 37151 (North, 1983).

- If confirmed, the multiperiodicity would be strong support for the arguments that stellar pulsations are responsible for the observed variations. This interpretation is also a plausible explanation why these objects are found in a apparently well-defined part of the HR diagram. On the other hand, the periods are very long and would indicate gravity modes with high l-values. Apart from the questions why just these modes are excited, the large colour variations also cast some doubt on this interpretation.

Burki's (1983) suggestion is still attractive, however, when we consider the analogy with the 53 Persei stars. If our sample were to be extended to the northern hemisphere, it would include 53 Persei itself and also ι Her on the basis of their colours and their scatter in the catalogue. In fact, the photometric variations of 53 Persei occur on a time scale of 2 days (Buta and Smith, 1979). Buta and Smith's argument on the small colour variations observed for 53 Persei does not affect the similarity, since they observed only in the Stromgren b and y colours, a spectral range in which we did not observe significant colour variations.

Our data could then also argue against the identification of the 2-day period of 53 Per with a non-radial pulsation mode. In turn, we feel that it could prove worthwhile to check our stars for the short-term profile variations typical for the 53 Per stars. It would then be a possibility that the ultra-short-period variability claimed by Jakate for HR 3467 was not spurious, but a transient phenomenon associated with the profile variations.

4. Concluding Remarks

In this paper, we have tried to establish a classification of the photometric variability of B stars in as unbiased a way as possible. The construction of the sample of program stars and the characterization of the different types were mainly based on strictly photometric parameters. In addition, all time scales, from a fraction of a night up to a few years, were considered.

To check the relevance of our classification, we reexamined the list of microvariable stars of Rufener and Bartholdi. It turned out that we described essentially all the variable B-stars, apart from some ellipsoidal or eclipsing binaries (Burki and Rufener, 1978, 1980; Waelkens and Bartholdi, 1982; Waelkens and Rufener, 1983c). None of the other stars that were intensively monitored in our program and the variability of which were confirmed indicate convincingly that other types of variability play a significant role.

Of course, our approach and thus our conclusions are statistical in nature and amplitude limited. Our results do not exclude isolated exceptional cases or a class of variables below our detection limit. Still, we are confident in the physical significance of our approach, since large and small amplitude variables do coexist for all known varicases, so that the "tip of the iceberg" is always present in our sample. In particular, we doubt the existence of a continuous distribution of pulsating variables between the Beta Cephei stars and the Delta Scuti stars, that would manifest itself in the "Maia sequence" (Breger, 1979). Our detection limit is well below the amplitudes sometimes claimed for these stars.

References

Balona, L.A., 1977, Mem.R.Astron.Soc. 84, 101.
Balona, L.A., 1982, Inf.Bull.Variable Stars No.2120.
Breger, M., 1979, Publ.Astron.Soc.Pacific 91, 5.
Burki, G., 1978, Astron.Astrophys. 65, 357.
Burki, G., 1983, Astron.Astrophys. 121, 211.
Burki, G., Maeder, A., Rufener, F., 1978, Astron.Astrophys. 65, 363.
Burki, G., Rufener, F., 1978, Astron.Astrophys. 70, 105.
Burki, G., Rufener, F., 1980, Astron.Astrophys.Suppl.Ser. 39, 121.
Buta, R.J., Smith, M.A., 1979, Astrophys.J. 232, 213.
Cox, A.N., 1983, in "Astrophysical Processes in Upper Main Sequence Stars", 13th Advanced Course of the Swiss Society of Astronomy and Astrophysics, p.1-165.
Cramer, N., Maeder, A., 1979, Astron.Astrophys. 78, 305.
Cramer, N., Maeder, A., 1980, Astron.Astrophys. 88, 135.
Golay, M., 1980, Vistas Astron. 24, 145.
Gronbech, B., Olsen, E.H., 1977, Astron.Astrophys.Suppl.Ser. 27, 443.
Harmanec, P., 1983, preprint.
Hauck, B., Mermilliod, M., 1980, Astron.Astrophys.Suppl.Ser. 40, 1.

Jakate, S.M., 1979a, Astron.J. 84, 552.
Jakate, S.M., 1979b, Astron.J. 84, 1042.
Jerzykiewicz, M., Sterken, C., 1977, Acta Astron. 27, 365.
Jerzykiewicz, M., Sterken, C., 1979, IAU Colloquium No. 46, p.474.
Jerzykiewicz, M., Sterken, C., 1981, "Nice Workshop on Pulsating B Stars", GEVON and C. Sterken, edrs.
Kukarkin et al., 1969, "General Catalogue of Variable Stars", Moskou.
Maeder, A., 1980, Astron. Astrophys. 90, 311.
Maeder, A., 1981, in "Nice Workshop on Pulsating B Stars".
Maeder, A., Rufener, F., 1972, Astron.Astrophys. 20. 437.
North, P., 1983, Private Communication.
North, P., Cramer, N., 1981, Liege Colloquium on CP Stars.
Percy, J.R., 1982, IAU General Assembly, Patras, Greece.
Rufener, F., 1981, Astron.Astrophys.Suppl.Ser. 45, 207.
Rufener, F., Bartholdi, P., 1982, Astron.Astrophys.Suppl.Ser. 48, 503.
Rufener, F., Maeder, A., Burki, G., 1978, Astron.Astrophys.Suppl.Ser. 31, 179.
Shaw, J.S., et al., 1983, Inf.Bull.Variable Stars No.2288.
Stepien, K., 1980, in "Variability in Stars and Galaxies", Liege, B5.6.
Valtier, J.C., et al., 1981, in "Nice Workshop on Variable B Stars".
Vander Linden, D., 1983, This Workshop.
Van Hoof, A., 1972, Astron.Astrophys. 18, 51.
Waelkens, C., Bartholdi, P., 1982, Astron.Astrophys. 108, 51.
Waelkens, C., Rufener, F., 1982, in "Pulsation in Classical and Cataclysmic Variable Stars", Cox, J.P., Hansen, C.J., edrs., p. 313.
Waelkens, C., Rufener, F., 1983a, Astron.Astrophys. 119, 279.
Waelkens, C., Rufener, F., 1983b, Astron.Astrophys. 121, 45.
Waelkens, C., Rufener, F., 1983c, Astron.Astrophys.Suppl.Ser. 52, 13.
Waelkens, C., Rufener, F., 1983d, Astron.Astrophys.Suppl.Ser. 52, 21.

DISCUSSION

UNDERHILL: I am wondering how much of your apparent variation could be due to rotation of a spotted disk when the amount of spots on the disk is changing slowly. I find your suggestion of rotation very attractive. I would suggest that you consider also that the disk is spotted and that the amount of spots is changing. Now, I would not expect to see a changing apparent rotation velocity shown by photospheric lines, because actually the speed of rotation is not changing. It is very difficult to think that that would change. But the amount of disk that is very bright in places and dark in other places may change; that would give you an apparent change in amount of light.

WEISS: From the experience with the Ap stars we can say that periodic changes of line profiles and equivalent widths are very sensitive proofs for the presence of spots. Even spots which are too small to produce photometric variations can be detected spectroscopically. Such observations would be cruical as a proof of our model.

UNDERHILL: Well, in the cases that Waelkens was reporting there are inadequate spectral observations. Ap stars have narrower lines and brighter. More study has been done. It might be profitable to put time into one or two of these variables at as high dispersion as possible.

WAELKENS: Even in some Ap stars, blocking and blanketing are not sufficient to explain the photometric variations, but some additional effects, such as an inhomogeneous surface temperature distribution, are required. I would not be surprised if the spectroscopic variations associated with the light variations of the stars I labeled "mid-B variables" were actually small. In fact, it is probably just because of that reason that they were not recognized as a class in earlier studies, which all were affected by some spectroscopic bias.

DOAZAN: It seems to me that some caution should be taken when interpreting photometric variations --- especially when they are restricted to the visual region only --- in terms of physical phenomena, without taking into account the variability exhibited by the spectral lines. Including spectral lines and other spectral regions --- far UV and X-ray --- may well raise problems for such an interpretation based on a purely geometrical effects, such as the rotation of a spot. Incidentally, how can you be sure that the stars in your diagram are Bp stars and not Be's, for example?

WAELKENS: The photometric method we used only fails to detect the Bp HgMn stars, which are known to vary little. As to the Be stars, we would not have detected those stars that show only emission in H alpha.

DOAZAN: But the distinguishing characteristic of a Be star is the presence of emission at H alpha, and there are lots of Be stars which do not show any other emission feature in the visible region.

WAELKENS: Certainly.

BOLTON: On Wednesday, I will show that it is possible to explain the helium spectrum variables by balancing magnetic field and stellar wind strengths. It is possible to suspend a cloud of helium in a localized area of the line forming region of the atmospheres of magnetic B stars. With the right combination of magnetic field and atmospheric structure, I think it would be possible to suspend the helium-rich layer at any level in the atmosphere. Thus, in some stars, it might be found at the level where it will affect the continuum but not show as a line strength anomaly. I haven't thought about this before, but my quick reaction is that this would require a weaker magnetic field and a lower effective temperature than is found in the classical helium-strong spectrum variables.

HARMANEC: I would like to add that Tom forget to mention that the spotted geometry is not the only possibility. They have considered also a belt geometry which is much more probable, much more acceptable physically, and should be thus seriously considered.

THOMAS: Explain to us, why is one more acceptable than the other?

HARMANEC: Because it has a rotational symmetry, for instance. And some rotation must be present, at least among other effects, in real stars.

THOMAS: So you will show something correlated with v•sin i?

HARMANEC: I shall show you some such correlations to rotational periods...

THOMAS: No, v•sin i ....

HARMANEC: ... in spectroscopy, but let us postpone that for tomorrow.

UNDERHILL: Considering the question of how big spots affect the light from a star that rotates is one way how one can make a model for a stellar atmosphere to account for the photometry. Another way is to say that you can have a group of spots in an equatorial belt, some of them changing position on the surface of the star, and have the star rotate. That will give a photometric impression of an equatorial belt changing its amount of light. The amount and distribution of the spots in the equatorial belt could change. Therefore, we must look at more than one geometry possible, at a pattern of dark and light regions, hot and cold perhaps, on the surface of the star to interpret these light changes. Their changes in the actual line shapes are really an effect of integration through the part of the atmosphere that lies above the continuum-forming region. That can be called a part of the mantle in some cases. It also can be affected by the heating, cooling, and density changes that occur above a spot region. There is very much freedom to build models. You may not recognize that you might have magnetic fields present. I think we cannot say anything definitely at this moment and I am looking forward to hearing more observational facts that can help us to separate between the possible models we can think of.

BOLTON: I think you are going farther than I, and possibly Petr, would go. I am not willing to go beyond the simplest geometry, polar spots and an equatorial band, until the observations force the introduction of epicycles.

THOMAS: Could I just ask: when you do your modelling - Wendesday, Tuesday, whenever - in addition to the distribution in position, would you give us a distribution in depths? Remember, we have some 20 stellar radii over which the spectrum is distributed from the far UV to the H alpha.

BOLTON: I will address that to some extent, yes.

BAADE: Judging from the program of the workshop, little will be said about the variability of supergiants, which, I think, is regrettable but also understandable since supergiants are not usually considered to be rapidly variable stars. I have been looking for non-radial pulsations due to an extension of the 53 Per-type variability into high-luminosity classes. With new observations, I think, I found this kind of pulsations in only one star and it seems that a mode of very high degree is excited. I have not yet worked out if these variations are periodic. But this might be one explanation why in some stars within the Beta Cep instability strip you did not see photometric variations since if the degree is high you would see nothing, because of the cancelation effects across the disk of the star. But my question regarding the supergiants is: Do you see also rapid variations and what is the lower limit of their time scales that you would estimate from your data? In most of the stars that I have observed I see some rapid changes of the line profiles but between these periods of activity the star seems to be fairly constant over a couple of days although the line profiles remain asymmetric.

WAELKENS: I did not spend so much observing time on supergiants and, in addition, was mostly interested in their variations on time scales of the order of some days. At least some stars did vary within one night, but I have no evidence for variability on a time scale as short as you mention. Also, I could not detect periods: the variations were rather irregular, perhaps similar to those of Be stars.

One interesting object to check for spectroscopic variability is HD 116084. It is certainly variable within one night, altough the main variability is on a longer time scale. In the HR diagram, it is situated near Ro Gem and your star.

BOLTON: I would like to comment briefly on the problems associated with the search for multiple periods. I have found that the standard methods for power spectrum or periodogram analysis of unequally spaced data can give noise peaks that look very significant. Unfortunately, these methods do not allow you to test the statistical significance of these peaks, so you can easily be led astray. This can be avoided by using the modified form of periodogram analysis described by J. D. Scargle (1982, Ap. J. 263, 835) and E. J. Groth (1975, Ap. J. Suppl., 29, 285), which allows statistical tests to be made on the significance of peaks that are found.

Unfortunately, it seems that even this may not be sufficient. Norm Walker and Dave Pike (RGO) have told me of experiments they have run on artificial data containing two periodicities sampled at intervals that are typical for real astronomical data. They find that it is possible to find a very large (infinite?) number of combinations of periods that will fit the power spectrum equally well. This is a dismaying result, if true.

WAELKENS: I would say that the accuracy must depend on the values of the periods and on the amplitudes, but I would not be as pessimistic as you are.

BOLTON: I think it is true that the correct periods can be identified correctly if they are very different, but their results seem to indicate that combinations of similar periods will be difficult to identify correctly unless a continuous data string stretching over at least several periods is available. My impression is that they found they needed something like 24 hours of continuous data in order to reliably identify two periods with lengths like those that are normally seen in Delta Scuti stars.

HARMANEC: Have you tried also Stellingwerf's PDM method? We did similar experiments and were able to recover several periods quite safely from non-equidistant data. But in principle I agree with what you said. The situation is especially bad if you deal with a double-wave curve, or any more complicated, highly non-sinusoidal variability. Then it is very hard to recover, or even to detect the period with the standard technique - with the exception of the PDM method.

BOLTON: Our limited experience with Stellingwerf's algorithm is that you can indeed recover multiple periods. However, my impression is that Walker and Pike tested this method and found the same problems as with the power spectrum technique.

HARMANEC: But if you use artifical non-equidistant data containing multiperiodic variation, you recover the periods safely with the PDM method.

BOLTON: According to what I gathered from Walker, you also find other period combinations which will represent the data as well, so if you have no a priori knowledge of which period combination to expect, there is a danger you will pick the wrong one.