DIAGNOSTIC VALUE OF BETA CEPHEI STAR PHOTOMETRY

C. Sterken
University of Brussels
Pleinlaan 2,
B-1050 Brussels, Belgium

M. Jerzykiewicz
Wroclaw University Observatory
ul. Kopernika 11
PL-51-622 Wroclaw, Poland

1. INTRODUCTION

Two definitions of a ß Cephei star are presently in use. The first embraces all variables of early B spectral type that have at least one period shorter than about 0.3 days. The second definition reserves the term "ß Cephei star" for the early B spectral type pulsators in which a radial mode is present. The first definition applies when an early B star is found to show short-period light or radial-velocity variations; the second brings some order into the picture of line-profile variability among B stars, since ß Cephei stars seem then to represent a particular case of a wider class of B type pulsators. The obvious advantage of the second definition is that it is based on a clear physical concept. However, it is often difficult to decide whether variations observed in a B star are due to a radial or to a nonradial mode. In practice we are thus left with the first, phenomenological definition.

Almost 150 stars have been classified over the years as members or possible members of the ß Cephei class on the basis of short periods seen in their light- or radial velocity variations. However, a convincing and well documented evidence of light variations with at least one period shorter than about 0.3 days is available for only 57 of them. These stars we consider to be ß Cephei variables. In spite of this rather vague concept, these 57 stars do not spread in the H-R diagram all over the early B range, but they concentrate in the same region as the few "classical" ß Cephei variables known since the mid-fifties (for a more complete discussion, see Sterken and Jerzykiewicz, 1991a).

The pulsation mechanism for ß Cephei stars has been sought for 30 years. Several different mechanisms have been considered, but none is widely accepted. Recently, Cox et al. (1990) have proposed that the problem would be solved by improved treatment of the iron lines in the opacity calculations. According to them, the sudden appearance of a tremendous number of iron lines, as the temperature rises above 150000 K, gives the high sensitivity of the opacity to temperature needed for the well-known κ effect to operate. They also believe that pulsation amplitudes are controlled by the iron abundance in the surface layers. A slight primordial deficit of iron would thus explain why not all B stars pulsate. On the other hand, large amplitude pulsations like those seen in BW Vul would indicate a somewhat larger iron abundance compared to other B stars.

In view of the promising prospect that the driving mechanism active in ß Cephei stars has been identified, it is instructive to look back upon other long-standing questions in ß Cephei star research. The ones for which conflicting opinions have persisted are the following:

1. Which are the boundaries (red- and blue boundaries) and the corresponding luminosity cutoffs of the instability region?
2. Do variable and non-variable stars coexist in the instability strip?
3. Is the ß Cephei instability strip of finite width, i.e. is the width of the strip (in the Q,ß or any related diagram) larger than the expected observational errors on the associated parameters?
4. Are the ß Cep stars in the core hydrogen-burning phase, or in the shell burning phase of evolution, or yet in another phase?
5. What is the frequency of occurence of ß Cep stars, and is this frequency compatible with their evolutionary state?
6. Do all the ß Cep stars pulsate in the same mode?

For each of these questions at least one answer has been formulated in the literature (for a complete review see Sterken and Jerzykiewicz, 1991b). Moreover, truly relevant answers are mostly based on long series of accurate photometric measurements. In this paper we review the kind of information that can be obtained by doing photometry, we discuss what should be observed in the future, and we describe how such observations should be done.

2. WHAT CAN BE FOUND BY PHOTOMETRY?

2.1 Presence of light variability.

Detection of light variability was one of the cornerstones of photometric research during the last couple of decades. We distinguish four different approach paths, viz.:

- Serendipitous discoveries of ß Cephei stars (e.g. HD 80383, Haug 1977)
- Systematic searches (Lynds 1959, Jerzykiewicz and Sterken 1977, Balona 1977, Balona and Engelbrecht 1983, Delgado et al. 1984, 1985)
- Monitoring of microvariables from catalogues (e.g. the Geneva Photometry Catalogue, Rufener and co-workers)
- Discovery and monitoring of eclipsing binary ß Cep stars (Jerzykiewicz et al. 1978, Engelbrecht and Balona 1986).

The abovementioned search- and monitoring programs failed to significantly extend the spectral type range occupied by ß Cephei stars beyond the limits set by Struve(1955). More than 95% of all ß Cephei stars are confined to the very narrow spectral type range from B0.5 to B2, but this is not so for the range in luminosity class, which has been extended downwards to class V. Most of the class V variables are members of the open clusters NGC 3293 and NGC 6231.

2.2 Absence of light variability.

An extremely useful by-product of ß Cephei star searches are the discoveries of constant stars. Besides their role as comparison stars for differential measurements, constant stars are fundamental marks in mapping the instability strip in any color-magnitude diagram. As such, they can only be used if they have been measured with the same photometric precision and at a similar rate of recurrence as were observed the variable stars.

The conclusion from these studies is that for the evolved stars the instability region is predominantly populated by ß Cephei stars, whereas in extremely young clusters such as NGC 6231 the population of the strip is of a mixed character. The incidence of non-variable stars in the instability strip seems to increase toward the ZAMS.

2.3 On-and-off variability.

Sometimes a star observed as constant may later turn out to be a ß Cephei star which was first observed with insufficient accuracy or during a specific time interval when the amplitude was below detectability level due to interference of the different periodic components. Such cases are reported by Balona and Engelbrecht (1983) for NGC6231-238, by Sterken and Jerzykiewicz (1983) for HR5488 and HR3058. This illustrates the difficulties related to the search for variables with such small amplitudes and short, multiple periods. One needs more than one night of excellent photometric quality to confirm the eventual ß Cephei character of a star.

In addition, the large number of very small amplitude variables among ß Cephei stars suggests that there may be stars in the instability strip with undetectably small light variations. It is not known how many stars belong to this category. These apparently constant stars may include radial and low ℓ nonradial pulsators having genuinely small amplitudes, as well as high ℓ pulsators, suffering from the effect of averaging the emergent flux variations over the stellar disk. Another type of nonradial pulsator with undetectable light variations may be represented by the primary component of the double-line spectroscopic binary α Vir (Spica). The star was discovered by Shobbrook et al. (1969) to show ß Cephei-type light variation with a period of 0.1738 days and a yellow light amplitude of 0.016 mag, in addition to an ellipsoidal variation with the system's 4-day orbital period and a range of 0.03 mag. In 1972 the short-period variations became undetectable (see Lomb 1978 for a thorough study of the decline of the star's pulsations). Recent observations by Sterken et al. (1986) and Balona (1989) show that only the 4-day ellipsoidal light variation can now be seen. Balona (1985) suggested that pulsations of the primary of Spica are now undetectable because of an unfavourable change in the inclination of the pulsation axis, caused by precession in the binary system. According to him, the observed decline of Spica's short-period variations can be accounted for by assuming a nonradial quadrupole mode and the period of precession equal to about 200 years. A small fraction of nonradial pulsators in the instability strip may appear non-variable because of this effect. While, however, in the case of a binary system such as Spica the hypothesis is verifiable, since the variations will periodically reappear as the inclination angle changes because of precession, it cannot be verified in the case of single stars. Large amplitude changes on a time scale of years do also occur in other ß Cephei stars, for example, in 16 Lac (Fitch 1969, Jerzykiewicz 1976, Jarzebowski et al. 1979).

On-and-off variability of a totally different kind has been suspected in the low-temperature extension of the ß Cephei strip. Some stars, like for instance 53 Arietis, have shown variability at some occasions, but not on others. Sterken (1988) showed that the ß Cephei-type variations which were repeatedly reported for 53 Ari, are in fact due to instrumental effects. 53 Psc may be a similar case (see Jerzykiewicz and Sterken 1990).

2.4. The character of the frequency spectra.

Many ß Cephei stars are multiperiodic. Except for the ß Cephei stars belonging to NGC6231, the range of frequencies which occur in a given star (without, of course, taking into account harmonics and cross-terms) is quite narrow. NGC6231 is that cluster where all ß Cephei stars lie very close to the main sequence.

In 12 Lac and ν Eri equally spaced frequency triplets are seen. They can probably be explained in terms of first order rotational splitting of a nonradial mode, but not necessarily an ℓ=2 one. However, rotational splitting alone does not account for other frequencies occurring in these two stars, and equally spaced frequency patterns were not found in ß CMa, KP Per, and 16 Lac. Thus, in some multiperiodic ß Cephei stars oscillations corresponding to different ℓ modes are simultaneously excited.

2.5. The long-term stability of the frequency spectra.

Some ß Cephei stars display strictly coherent oscillations over time intervals of several years (12 Lacertae; Jerzykiewicz et al. 1984). Secular frequency changes, detected in ß Cephei stars such as σ Sco, BW Vul, ß Cep (for an analysis, see Chapellier 1985), are very small. The sign and rate of period changes could reflect the evolutionary change of the radius of a star. This rate can be either fitted to models representing intervals of constant period between episodes of abrupt period change, or to models of period change at a constant rate. Such abrupt jumps have no evolutionary significance, and the average rate of change can be used to determine the evolutionary state of a star provided that non-evelutionary period changes do not interfere.

2.6. The wavelength dependence of the amplitude of variation.

The amplitude of light variability of some ß Cephei stars increases when going to shorter wavelengths. The most extreme case is BW Vul (see fig. 3 in Sterken et al. 1987). Stamford and Watson (1977) have showed that the wavelength dependence of the amplitude can be used to derive ℓ. This method has been applied by Watson (1988) to a number of ß Cephei stars for which the ultraviolet and visual amplitudes are known. The results indicate the presence of both radial (ℓ=0) and nonradial (ℓ>0) pulsation modes. According to them, nonradial and radial modes coexist in ν Eri and σ Sco. In ß Cep, ß Cru, Spica, τ^1 Lup, and λ Sco, the single observed mode is nonradial. The other singly-periodic variables considered by Watson (1988), for example, δ Cet and BW Vul, have the ultraviolet and visual amplitudes indicating ℓ=0. An important case, discussed in some detail by Watson (1988), is that of V386 Cen. The light variation of this star, discovered by Waelkens and Rufener (1983), consists of three short-period sinusoidal components. According to Watson (1988), all three components have the ultraviolet to visual amplitude ratios favouring the ℓ=1 or ℓ=2 modes. In other words, V386 Cen is a multiperiodic ß Cephei star in which no radial mode is seen.

2.7. Photometric indices and position in the observational H-R diagram.

Evidence and conclusions discussed in sections 2.1 to 2.6 do not strictly depend on the photometric system that is being used. On the contrary, discussion of colour-magnitude diagrams and the position of ß Cephei stars therein, is only valid if the measured quantities are expressed in a standard system. Complete standardisation involves two steps: one must observe photometric standard stars for transforming the instrumental colour indices to standard values, and one must observe astrophysical standard stars in terms of effective temperature and of absolute magnitude. This makes sense since ß Cephei stars are - except for the presence of pulsation - absolutely "normal" B stars.

When observing photometric standard stars one should very carefully chose the standard stars, cautiously select the catalogue with photometric indices of these standard stars, and properly set up the filter-detector-telescope photometric configuration. For a discussion of the astrophysical consequences of improper standardisation, we refer to Sterken and Manfroid (1987).

Only a few ß Cephei stars are among the 32 stars for which Code et al. (1976) determined effective temperatures and bolometric corrections from a combination of satellite absolute fluxes and interferometrically determined angular diameters. These data are the basis for several calibrations of photometric indices in terms of effective temperature and bolometric corrections (see Sterken and Jerzykiewicz 1991b). As far as the absolute magnitude scale is concerned, one must rely on the main-sequence fitting procedure. Fortunately, recent uvby and ß photometry of a number of young galactic clusters made it possible to significantly improve Crawford's (1978) B star calibration. For a detailed discussion we refer the reader to Balona and Shobbrook (1984).

3. FUTURE PHOTOMETRY

If the state of theory is such that the problem of identifying the pulsation mechanism has been solved, one should proceed to tackle the problem of the process which limits the pulsation amplitude, and the mechanism of pulsation mode selection. A prerequisite is accurate knowledge of pulsation modes of all ß Cephei stars, as well as the pattern of the long-term changes of the amplitude.

For what concerns the last issue, regular multi-site monitoring over several seasons of specific stars such as 16 Lac, Spica, BW Vul and σ Sco should be carried out. Pulsation modes can be identified by using simultaneously collected high-resolution multi-colour photometry and line profile data of the brightest ß Cephei stars. In addition, one should systematically search for other ß Cephei stars that are members of eclipsing binary systems, so that the number of astrophysical standards can be increased.

4. OBSERVING STRATEGIES

Breakthroughs in pulsating B star research have come from large volumes of data of high accuracy, mainly collected during searches and monitoring campaigns. Such work was tedious and very time consuming, and this will also be the case for the work outlined in section 3. A promising alternative is the use of a network of dedicated automatic telescopes using identical instruments at a number of good-quality sites.

Automatic telescopes represent a novel concept leading to a radically new way of conducting observations, characterised by short integration time and short time intervals between successive measurements. Moreover, automatic telescopes specifically built for observing without human assistance, always have an edge over conventional telescopes, even over those which are computer-controlled, since they move more quickly from star to star. Automatisation however does not by itself imply higher precision since much depends on the programmation of the instrument (see Sterken and Manfroid 1991).

REFERENCES

Balona, L.A.: 1977, Mem. R. astr. Soc. 84, 101.
Balona, L.A.: 1985, Mon. Not. R. astr. Soc. 217, 17P.
Balona, L.A.: 1989, private communication
Balona, L.A., Engelbrecht, C.: 1983, Mon. Not. R. astr. Soc. 202, 293.
Balona, L.A., Shobbrook, R.R.: 1984, Mon. Not. R. astr. Soc. 211, 375.
Chapellier, E.: 1985, Astron. Astrophys. 147, 135
Code, A.D., Davis, J., Bless, R., Hanbury Brown, R.: 1976, Astrophys. J. 203, 417.
Cox, A.N., Morgan, S.M., Rogers, F.J., Iglesias, C.A.: 1990, This conference
Crawford, D.L.: 1978, Astron. J. 83, 48.
Delgado, A.J., Alfaro, E.J., Garcia-Pelayo, J.M., Garrido, R., Vidal, S.: 1984, Astron. Astrophys. Suppl. Ser. 58, 447.
Delgado, A.J., Alfaro, E.J., Garrido, R.: 1985, Astron. Astrophys. Suppl. Ser. 61, 89

Engelbrecht, C.A., Balona, L.A.: 1986, Mon. Not. R. astr. Soc. 219, 449.

Fitch, W.S.: 1969, Astrophys. J. 158, 269.

Haug, U.: 1977, The Messenger 9, 14

Jarzebowski, T., Jerzykiewicz, M., Le Contel, J.-M., Musielok, B.: 1979, Acta astr. 29, 517.

Jerzykiewicz, M.: 1976, Multiple Periodic Variable Stars, ed. W.S. Fitch (Academic Press, Budapest), Part 2, p. 39.

Jerzykiewicz, M., Borkowski, K.J., Musielok, B.: 1984, Acta astron. 34, 21

Jerzykiewicz, M., Jarzebowski,T., Musielok, B., Le Contel, J.-M.: 1978, Inf. Bull. Variable Stars No 1508

Jerzykiewicz, M., Sterken, C.: 1977, Acta astr. 27, 365.

Jerzykiewicz, M., Sterken, C.: 1990, Astron. Astrophys. 227, 77

Lomb, N.R.: 1978, Mon. Not. R. astr. Soc. 185, 325.

Lynds, C.R.: 1959, Astrophys. J. 130, 577.

Shobbrook, R.R., Herbison-Evans, D., Johnston, I.D., Lomb, N.R.: 1969, Mon. Not. R. astr. Soc. 145, 131.

Stamford, P.A., Watson, R.D.: 1977, Mon. Not. R. astr. Soc. 180, 551

Sterken, C.: 1988, Astron. Astrophys. 189, 81.

Sterken, C., Jerzykiewicz, M.: 1983, Acta astr. 33, 89.

Sterken, C., Jerzykiewicz, M.: 1991a, in "Confrontation between Stellar Pulsation and Evolution", Astron. Soc. of the Pacific Conference Series Vol. 11, p. 236 (eds. C. Cacciari and G. Clementini).

Sterken, C., Jerzykiewicz, M.: 1991b. Space Science Reviews, In Press.

Sterken, C., Jerzykiewicz, M., Manfroid, J.: 1986, Astron. Astrophys. 169, 166.

Sterken, C., Manfroid, J.: 1987, in: Observational Astrophysics with High Precision Data, Proc. 27th Liège International Astrophys. Colloquium, p. 55.

Sterken, C., Manfroid, J.: 1991, in: Precision Photometry: Astrophysics of the Galaxy, eds. A.G. Davis Philip, R. Bell. In Press.

Sterken, C., Young, A., Furenlid, I.: 1987, Astron. Astrophys. 177, 150

Struve, O.: 1955, Publ. astr. Soc. Pacific 67, 135.

Waelkens C., Rufener, F.: 1983, Astron. Astrophys. 119, 279

Watson, R.D.: 1988, Astrophys. Space Sci. 140, 255

DISCUSSION

A.W. FULLERTON: This morning I presented radial velocity curves that strongly suggest the presence of radial pulsations in the O7 II star HD34656. Its period is very close to 8.20 hours. Should I refer to this object as a β Cep variable, even though it represents a considerable extension of the "classical" β Cep instability strip?

C. STERKEN: The period is just too long to fit the purely phenomenological definition we gave. For what concerns the extension of the instability strip, one should not forget that for example V986 Ophiuchi lies well off the locus of all other β Cep stars.

M.A. SMITH: The last statements of your talk are not so much a criticism of automated telescopes as they are of single-element detectors (photocells). Much of this accuracy, and more, can be recovered by doing photometry with a CCD.

C. STERKEN: Not really. My argument is that automatization does not automatically lead to higher precision. Photometric accuracies of two to three thousandths of a magnitude were achieved already half a century ago. Sure, CCD photometry (if properly done) can yield even higher precision.

M.A. SMITH: The sudden jumps of the period in BW Vul that you showed from Chappellier's work could be a signature of chaos, which would be expected in a very large amplitude pulsator near the surface. A recent period change in a DAO white dwarf pulsator by Winget's group is smoothly varying as would be expected in a smaller amplitude pulsator, where by "small amplitude" I mean relative to the sound speed in the region of excitation of the white dwarf pulsations.

J.R. PERCY: (1) With regard to increased photometric precision: methods are available to achieve precision of 0.003^m or better, but not all observers can or will follow these methods!
(2) With regard to the supposedly discontinuous period changes in BW Vul: the difference between the "discontinuous" and the "continuous" models is small compared with the parabolic trend. We should not forget this evolutionary period change while disputing the fine details.

C. STERKEN: It is not so important whether the period changes are smooth or abrupt, but what counts is the average rate of period change, which, in the case of BW Vul, amounts to an increase at a rate of 2.7 seconds/century. If the period changes are caused by non-evolutionary effects, the sign of the period change will even reverse.

D. BAADE: Can the sudden period changes in BW Vul be explained in terms of a changing shape of the light curve?

C. STERKEN: No. From the 1982 photometric campaign on BW Vul it was clear that the light curve is stable. True, the shape of the stillstand phase may influence the time of maximum of the light variation, but when one uses times of minimum instead, one can study the period variation independently from the shape of the light curve.