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SPECTROSCOPY AND PHOTOMETRY OF SOME INTRINSIC B VARIABLE STARS

M. Alvarez[1], D. Ballereau[2], J.P. Sareyan[3], J. Chauville[2], R. Michel[4] and J.M. Le Contel[3]

[1] Instituto de Astronomía, Universidad Nacional Autónoma de México.
[2] Observatoire de Paris-Meudon.
[3] Observatoire de Nice.
[4] Escuela Superior de Ciencias, Universidad Autónoma de Baja California.

RESUMEN. A partir de estudios recientes que estamos llevando a cabo, reportamos algunos resultados preliminares que hemos encontrado. V 1294 (HD 184279) es una estrella B en emisión bien estudiada que muestra una envolvente (shell) permanente. A partir de observaciones fotométricas y espectroscópicas llevadas a cabo desde 1956 hasta la fecha, se puede establecer que cerca de 1968 se inició una fase activa en la envolvente que parece tener un pseudo-período de 60 meses. Esta estrella muestra además, evidencia de fenómenos de corta duración. 11 Cam (HD 32343) es una Be "vista desde el polo" que muestra también fluctuaciones cuasi-periódicas del orden de pocos días y quizás de horas. LQ And (HD 224559) es una estrella Be a la que se le ha detectado un período fotométrico de 0.31 días, similar a los de las estrellas β CMa (¿o un doble período de 0.62 días debido a rotación?). Nuestras observaciones espectroscópicas en Hα, parecen confirmar el período de 0.31 días. BW Vul (HD 199140), que es una estrella β CMa clásica, muestra un doble máximo en la curva de luz, detectable en los filtros rojos e IR. ¿Es la periodicidad de corto período observada en las estrellas B en emisión diferente a la que se produce en las estrellas β CMa?

ABSTRACT. From recent studies of the variability of Be stars we report some preliminary results found. V 1294 Aql (HD 184279) is a well studied emission star with a permanent shell. Photometry and spectroscopy from 1956 to date have allowed us to establish the start of an active period around 1968 that shows a pseudo-periodic behaviour of the order of 60 months. This star also shows short-lived phenomena. 11 Cam (HD 32343) is a Be pole-on star also showing quasi-periodic fluctuations of the order of a few days and possibly hours. LQ And (HD 224559) is a known Be star detected to show a photometric period of 0.31 days, similar to the β CMa stars (or a 0.62 day double wave phenomenon?). Our spectroscopic Hα observations seem to confirm the same 0.31 day period. BW Vul (HD 199140), a classical β CMa star, shows a double maximum in light detectable at red and IR colors. Is the short-term periodicity behaviour observed in the Be stars different to the one produced in the β CMa stars?

Key words: PHOTOMETRY — SPECTROSCOPY -- STARS-BE

I. MOTIVATION

Within the intrinsic B variable stars, several types were established as shown in Table 1.

a) The β CMa (or β Cep) stars, showing RV and light periodic variability, with periods of a few hours, light variability of < 0.1 mag. and relatively large RV variations < 150 km s^{-1}, showing a phase lag of about 0.25 period between these curves. Recently, and due mostly to new detection techniques, many stars of this same class have been found with smaller amplitude variations (a few thousands of a magnitude) and smaller RV variability (of several km s^{-1}). The physical picture that seems to be the most respected one to date is that the photosphere of the star pulsates with radial modes, although there is evidence that some of these stars present different and more sophisticated modes of pulsation. Theories still do not explain satisfactorily the observed phenomena. To try to understand the physical picture of these stars, simultaneous spectroscopic and photometric observations combined with a longitude coverage of repeated cycles have been shown to be a necessary tool. Several campaigns on particular stars have produced very important results as for example in BW-Vulpeculae, α-Lyrae, LQ-Andromedae, etc.

b) The Be variables: most of them show variability in several time scales ranging from years, months and even days. Recently, it has been found that some of them show variability with characteristic times of several hours. The observed variations are periodic in several cases, although in many others, there are impressive changes in which the emission features disappear for several years (becoming a "normal" B star without emission). Inversely, there are several B "normal" stars that have become emission stars. A few examples show both stages in their observed life. The observed variability has also been found in photometry due to surveys done with several systems: 13-color, ubvy-Hβ, UBV, etc. Recently, due also to new techniques and a different approach to the study of Be stars, it has been possible to detect variability on a shorter time scale, having found several stars with periodic variations of similar characteristics as those found in the β CMa group. As in those stars, the simultaneous studies including the longitude coverage have shown their importance. Observations done of 11 Cam and LQ And are reported in this paper.

TABLE 1. Variable B Stars.

Variable type / Period or time constant	β CMa or β Cep Maximum frequency - B2 Intrinsic	Mid B (B3-B7) 53 Per (?) (09-B6) Intrinsic	B emission/shell Maximum frequency - B2 Intrinsic (?)	He (strong), Bp > B3 Oblique rotator (?)	He (weak), Bp B4-B9-Ap Oblique rotator
Years (Activity ?) Continuous survey	Yes (?) 16 Lac, α Vir	(?)	Yes (most of them) Spectroscopy (Meudon, ...) Photometry (13C, ...)	(?)	Yes (?)
Days (Rotation ?) Longitude coverage necessary	Difficult detection for small amplitudes	Photometry - yes ubvy-Hβ Amplitudes >> 0.05 Spe -oscopy - yes Line profile fitting technique	Variables found in clusters Balona and Engelbrecht (1985, 1986) Baade (1986) McNamara (1986)	Yes	Yes
Hours (Pulsation ?) Longitude coverage, simultaneous spectroscopy and photometry	Yes High precision Few well known since 1902	Yes Some with well determined periods (e.g. i Her)	Yes (?) Some with known or suspected periodicity (LQ And, 11 Cam, Pleione, ...)	Yes	(?)

c) Other types of B variables exist, some of them detected by spectroscopic techniques and showing line profile variability and no detectable light changes. These stars (a small sample) were called "53 Per" variables, when first found and reported by Smith (1978). Recent surveys have been done of stars in and around the box in a H-R diagram where the short period β CMa variables are found. Other B variable stars have been found, called "mid B stars" by Waelkens and Rufener (1985). These two groups seem to be similar in many aspects.

d) There also exist the He strong variables and the ultra-short period variables (USPV) that are also within the same region in the H-R diagram.

e) It seems that all the above groups show variability due to intrinsic physical phenomena that produce the observed features. Other types of variable B stars also exist (Bp, eclipsing B binaries) that show periodic light and spectral variability due to the presence of the companion. It is easy to separate this group of stars from the intrinsic variable stars of the other classes.

The interest of three different research groups to observe, classify and try to understand the mechanisms that produce the observed variability in these B stars has been the motivation to start, several years ago, a collaborative effort between some observers of the spectroscopy group of the Meudon-Paris Observatory (LA 337), the "Groupe Etoiles Variables de l'Observatoire de Nice" (GEVON) and the photometry group of the San Pedro Mârtir Observatory in Baja California. In the following section, a summary of some of the preliminary results that we have obtained is given. It is presented in such a way that the particular research interest of the observers is emphasized.

II. LONG-TERM VARIABILITY OF Be STARS (HD 184279 AS AN EXAMPLE)

From the Meudon survey, we have looked for a star with a good coverage in order to study its long-term behaviour.

HD 184279 (V 1294 Aql) is a B0.5 IV-V emission star with V sin i = 245 km s^{-1}. It presents a permanent shell of hydrogen, neutral helium, Fe III, Ca II, Mg II and in some cases also Si II, Ni II and Fe II. This shell varies in strength and radial velocity (RV). Previous observations collected by Horn *et al.* (1982) show that an activity period of this star started around 1968, after a relatively quiet stage as an emission star. The V magnitude of this star continually decreased until 1974-1975 and then started to increase until 1977-1978, where it reached a maximum showing a rapid decrease in magnitude. Our 13-color photometric observations show the same behaviour. Photometry showed another minima in 1979-1980 and another maxima is expected to be present around 1985-1986. An analysis of the spectroscopic observations collected since 1976, has permitted us to point out the following interesting results, as shown in Figure 1.

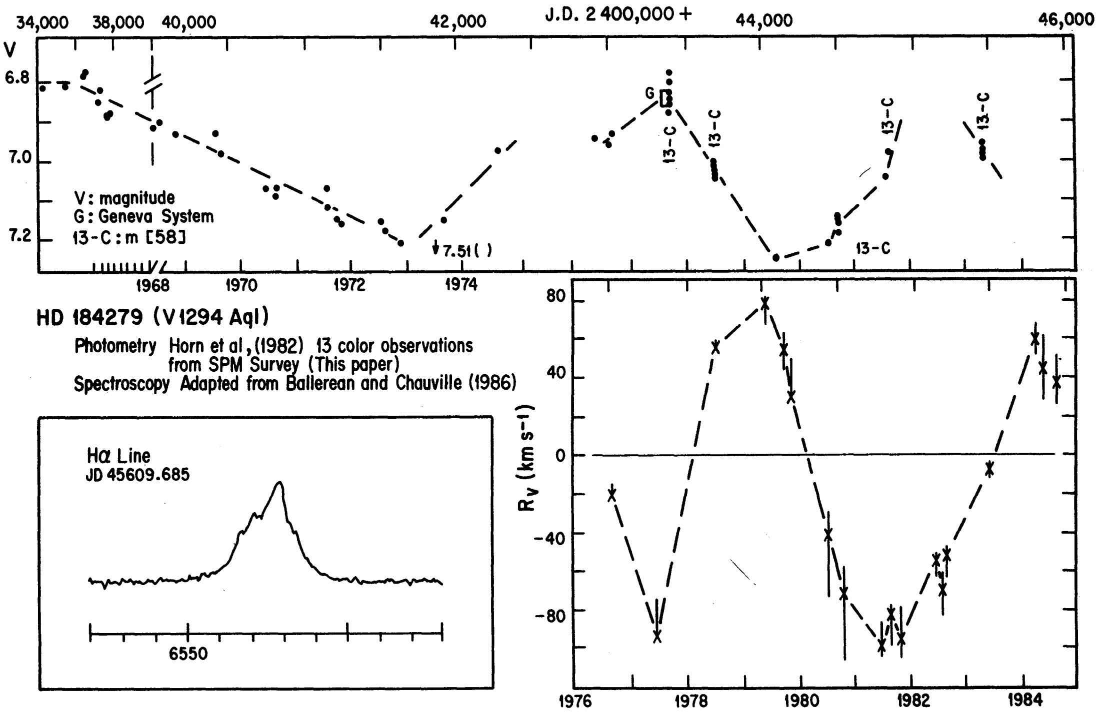

Fig. 1. Data on HD 184279.

1) The RV of several shell elements follow pseudo-cyclic variations in phase, with an average amplitude of 100 km s^{-1}. Two minima have been observed, by mid 1977 and mid 1981, with a maximum occurring by mid 1979. Some observations made in July 1985, show a new maximum at this epoch.

2) The RV of shell Balmer components undergo spectacular changes according to phase. At maximum phase (1978-1979) the Balmer progression is flat. During the epoch of constant decreasing RV (mid 1979-1981), the Balmer progression is strongly negative. The RV gradient between higher and lower terms, overlaps by as much as 50 km s^{-1}.

3) Mid and short-term RV variations are observable particularly in 1981 and 1982. Amplitudes of as much as 10-20 km s^{-1} are observable.

4) The lower Balmer terms observed in our set of IIaO photographic plates (Hβ, Hα, ...) present strongly variable violet and/or red emission components. The Hβ emission profile changes from P-Cygni to anti-P-Cygni at different phases of the RV curve. In 1982, emission was very important and was visible on both sides of the central reversal. The quotient V/R followed the same RV law as that of the shell lines.

5) Some observations made in July 1985, show a double structure on the Balmer lines. It started on July 14th and was very clear on July 27th. Four days later, the blue component was completely separated from the permanent one. One day later, it had completely vanished. From the final RV of this shortward component on Hβ (-140 km s^{-1}) and under the assumption of a shock wave propagating with a constant acceleration over four days, the distance covered would be about 5 R_*. With this observed phenomenon the thickness of the envelope around the star can be measured directly and it agrees with the dimensions of the elliptic-disk model calculated by an indirect method, as shown by Ballereau and Chauville (1986).

III. PROBABLE SHORT-TERM VARIABILITY (THE CASE OF 11 CAM)

Another interesting Be star studied in our program is HD 32343 (11 Cam), a well known "pole-on" star with V sin i = 131 km s^{-1} and well studied long-term spectroscopic variations as seen from the Meudon surveys. Important changes occur over years in the emission of the hydrogen lines until Hε. This emission vanishes sometimes for the higher terms of the Balmer series (Schild 1973). Shorter time scale variations were pointed out by Lund (1978), who detected them over a few minutes with a video-scan technique. Photometric studies carried out by Percy, Jakate and Matthews (1981), show that there is a probable variation of 0.02 mag. in a few hours. We observed this star at the San Pedro Mãrtir Observatory in Baja California with the Echelle spectrograph at the Cassegrain focus of the 212-cm telescope. Spectra were obtained in December 1985 on Kodak 09802 spectrographic plates with 20 min. exposure time, each half an hour, over four consecutive nights. The spectral field goes from 5000 Å to the end of the Balmer series. Up to now, we have carried out measurements only on the Hβ line profiles. The plates have been digitalized on a PDS microdensitometer and the noise filtered out by a Fourier Transform smoothing technique. The dispersion at Hβ is 8 Å mm^{-1}, the spectral resolution obtained is 0.34 Å and the signal to noise ratio reaches about 40 to 50. The method of analysis used has been described by Chauville (1985).

Preliminary results of these observations have been reported by Chauville *et al.* (1986) and a more complete analysis is under way. In Figure 2, we show a sequence of Hβ profiles obtained for this star.

Unfortunately, we could not obtain simultaneous photometric measurements because of poor weather conditions. We observe line profile variations from one spectrum to the next, so that the time constants involved appear shorter than previously supposed from photometric studies. A strong absorption appears clearly from time to time in the blue wing of the emission line. The central depth of the photospheric component also seems to vary, but this has to be confirmed as it strongly depends on continuum determinations. Although short time scale variations are obviously present, no periodicity could be found from the analysis of our scarce data (radial velocity, equivalent widths, etc.) and we cannot conclude about its existence. A precise photometric period is necessary to correlate information about rapid variations: sudden events may appear, with or without periodicity and a profile may vary without large effects on the equivalent widths. The same analysis remains to be carried out on the other Balmer lines, in order to detect an eventual correlation with Hβ variations and to study their time dependency.

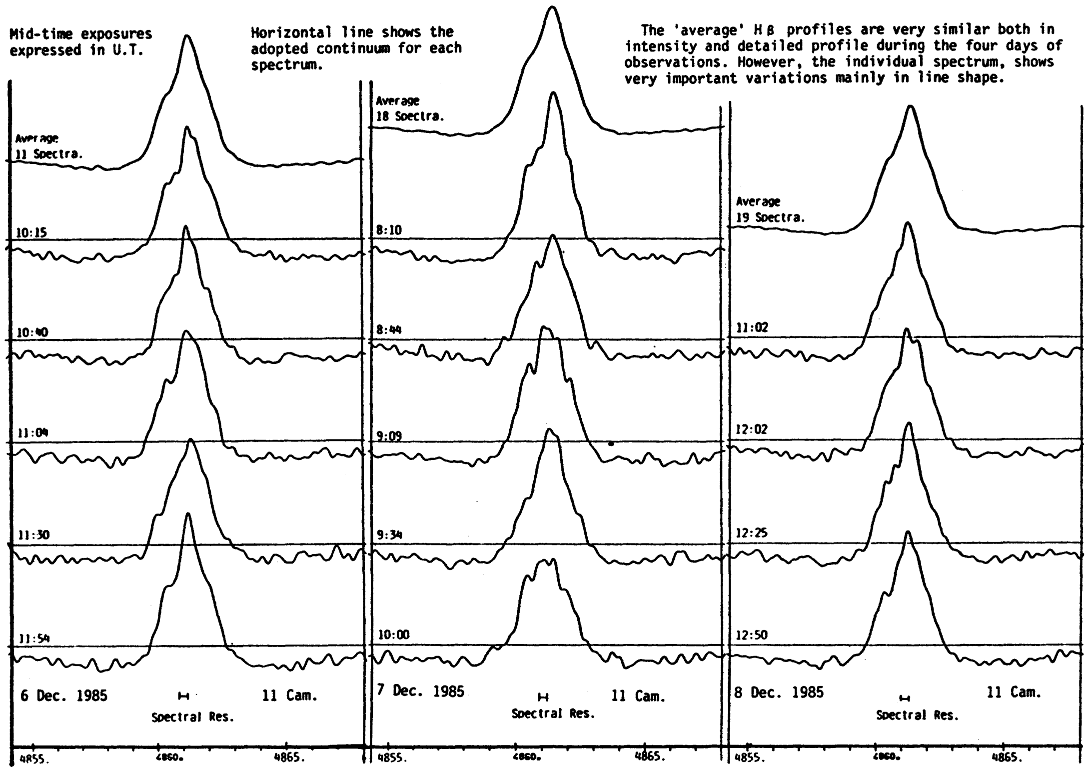

Fig. 2. Hβ profiles of 11 Cam, taken on December 6,7,8 and 9, 1985.

IV. NEW EVIDENCE ON A WELL KNOWN β CMa STAR (BW VUL)

HD 199140 (BW Vul) is a classical β CMa star with a well determined period of 0.201030 days, exhibiting one of the most pronounced variabilities, both in light Δ(1000 Å) ∿ 1.2 mag., Δ(3300 Å) ∿ 0.2 mag., Δ(K) ∿ 0.1 mag. and radial velocity Δ(RV) ∿ 190 km s^{-1}. During August 1984 and 1985 (Alvarez and Michel 1986), we observed this star with the 13-color photometric system in order to study its behaviour, not only in the UV and V wavelengths but also in the red part of the spectrum. The light curve shows a double maximum for wavelengths longer than 5800 Å. Barry *et al.* (1985) found, very clearly, this double maximum mainly in the IR (J and K filters). From simultaneous spectroscopic and photometric analyses, the first (and minor) maximum is coincident with the "standstill" normally observed at short wavelengths. The second (and well studied) maximum occurs at the moment where there is an abrupt change in the RV curve (going from +100 km s^{-1} to -40 km s^{-1}). The observed features seem to be consistent with a sudden ejection of a tiny envelope that, by the effect of gravity on this slow rotator (V sin i = 26 km s^{-1}), falls back again into the photosphere of the star. The radial pulsation model is consistent with the observations, opacity changes also seem to explain the abrupt changes observed in the RV curve.

V. IS THERE ANY Be PULSATING STAR? (THE LIMITING CASE OF LQ AND)

The short-term variability studies have been the main frame of interest between the research groups of the Nice Observatory and their counterpart at the San Pedro Mártir Observatory. Our collaboration started several years ago in order to observe some Be stars, for which short time scale variations or periods under one day were claimed. This is part of a program, initiated in Nice, to make a systematic exploration of the intrinsic B variables found around the so-called "instability strip" of the classical β CMa stars.

a) For both groups of stars a maximum of abundance is clearly present at B2, so we wondered if an eventual correlation existed between pulsation and emission phenomena.

b) Some β CMa stars are already known to show or to have shown (weak) emission, although it seems that there is no systematic survey on the Hα line in these variables.

c) Among the few Be stars that show short time constants, we have chosen to observe 11 Cam and LQ And (HR 9070) for which a constant period seemed to be well established according to Percy (1983). HR 9070 is specially interesting as its spectral type (B4 Ven) makes it an eventual short period pulsator just outside the β CMa strip (that for historical reasons, shows a strong cut-off at B3). For the last three years, we have observed this star from Europe and Mexico, both in spectroscopy and photometry, with simultaneity and longitude collaboration whenever possible. An example of the obtained photometry is shown in Figure 3. No color variation appears between ultraviolet and blue filters, so the star is different from the β CMa stars, where a strong color difference is observed due to the photospheric temperature variation. Of course, this fact is not contradictory with high order non-radial pulsations (another possibility for some β CMa stars). We have been unable to discriminate between a 0.310 day period due probably to pulsation of the stellar photosphere, or a double wave period of 0.620 days, probably due to a rotation of a feature on the stellar surface. Both possibilities give similar r.m.s. errors (there is no significant improvement when the 1983 to 1985 data are analyzed with a combination of up to five harmonics of the 0.620 day period). We have been able to derive an ephemeris for the maximum of the light curve HJD(T_{max}) = 2,445,618.606 + 0.310037 * E which fits the whole of the 1975 to 1985 data, although separately the 1975 to 1981 data (mostly Percy's work), is slightly better represented by a 0.309791 day period (and/or a double wave with a 0.619582 day period). The spectral variations obtained on the features of the Hα emission line show, when plotted according to the above ephemeris, a good agreement with the shortest 0.310 day period as shown in Figure 4. Important discontinuities appear around phases 0.0 and 0.6.

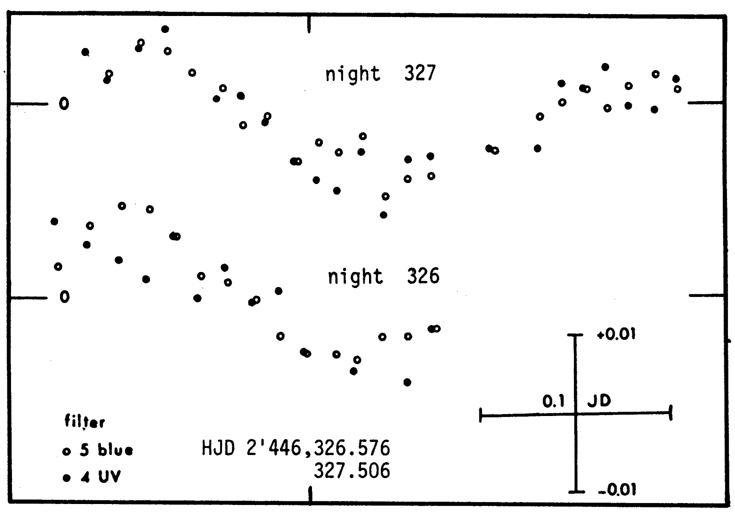

Fig. 3. Photometry of LQ And obtained on September 1985 with narrow filters UV: (λ3490 A) and B: (λ4740A). No color variation is clearly observed. Observed amplitude for this star is ≅ 20 - 30 m mag. This figure and also Figure 4 have been adopted from Sareyan *et al.* (1986).

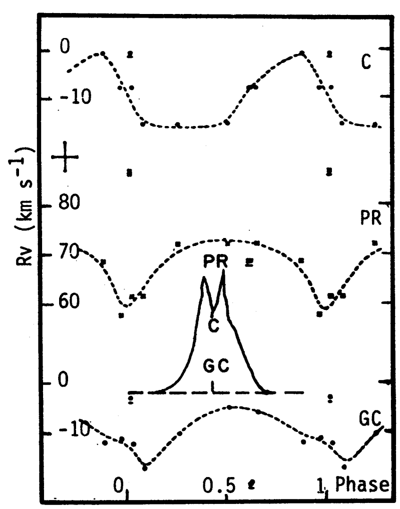

Fig. 4. Spectral variations on the Rv of the Hα emission line of LQ And plotted as a function of phase with the 0.310037 day period.

VI. SUGGESTIONS ON THE POSSIBLE EXPLANATIONS

The actual evidence does not allow us to differentiate clearly on the two distinct possibilities, either pulsation with a 0.31 day period or a spotted rotator with a 0.62 day period. Of course a multiple spot rotator could show the 0.31 day period as well.

a) If HR 9070 is a pulsator, then a medium or high order 'g' mode or a 'r' mode has to be invoked to account for the 0.31 day period in a B4 V star. For some stars considered as non-radial pulsators (NRP), Vogt and Penrod (1983) and Waelkens and Rufener (1983, 1985) have found similar periods. The mathematical models that can be invoked for the observations are such that the principal mode (the radial, l = 1) is excluded and the 'free' parameters can be adjusted to fit the observations. Is the star so complicated as to adjust itself to exclude the 'natural' modes and show only the 'g' or 'r' modes?

b) If the star is a spotted rotator, then we can consider that two spots could explain the appearance (and eventual variations) of the double wave curve as a function of time. However, in this kind of a model, there is a large degree of freedom, that allows us to account for the observations (number of spots or streams, eventual latitude migration, rotation gradient, progressive appearance and/or reinforcement of the features, etc.). Some authors consider that rotation of spots and/or streams could be a general phenomenon in Be stars (Balona and Engelbrecht 1985, 1986; Pavlovski 1983) and could explain the short periodic variation in these stars. Is there an EXCLUSION MECHANISM, probably related to the rotation of the star and/or to the inclination angle, between the β CMa pulsation and the Be phenomena within the same region of the HR diagram? For the Am and δ Scuti stars this exclusion mechanism exists in the lower part of the cepheid instability strip.

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Manuel Alvarez: Observatorio Astronómico Nacional, Instituto de Astronomía, UNAM, Apartado Postal 877, 22830 Ensenada, Baja California, México.
Dominique Ballereau and Jacques Chauville: Observatoire de Paris-Meudon, 5 Place Jules Janssen, 92195 - Meudon Principal Cedex, France.
Jean-Michel Le Contel and Jean-Pierre Sareyan: Observatoire de Nice, BP 252, 06000 Nice, Cedex, France.
Ramón Michel: Escuela Superior de Ciencias, UABC, Ensenada, Baja California, México.