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Correlated Spectroscopic and Spectrophotometric Behaviours of Be Stars

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Abstract. Correlations between long-term spectrophotometric and optical spectroscopic variations are investigated in some Be stars. Using spectrophotometric variations as a function of time and a compilation of spectroscopic measurements, we investigated temporal variations of emission and shell line parameters. In some cases time lags between spectroscopic and spectrophotmetric variations could be estimated. We could not find precise relations between the spectroscopic and spectrophotometric behaviours, but a number of tendencies could be derived which give information on physical parameters of circumstellar envelopes in Be stars.

1. Introduction

The Be star sample size that can be studied is greatly limited by the small number of objects which have been intensively monitored quasi-simultaneously in the past, both by photometry and spectroscopy. For selected objects spectrophotometric (SPh) correlations $(V,D,\Phi_{\rm rb})$ = f(time) were drawn from Moujtahid et al. (1998); compilation of spectroscopic measurements published in the literature and those contained in Meudon group archives as a result of OHP spectral analyses enabled us to investigate temporal variations of emission and shell line parameters such as equivalent width W_λ, peak separation $\Delta V_{\rm peaks}$, V/R ratio of emission lines (mainly Hα) and shell line radial velocity RV (Balmer and/or FeII). The relation $\Delta V_{\rm peaks}$ = f(W_λ) was sought for Hα and/or Hβ emission lines.

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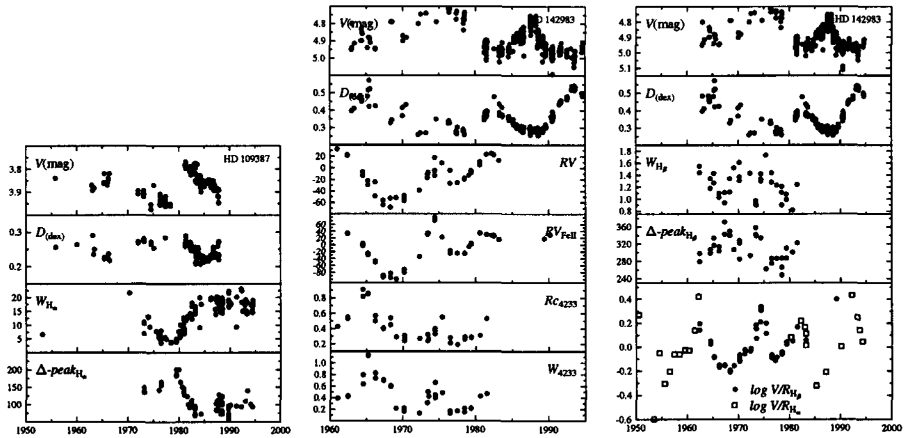

Figure 1. Comparison of spectrophotometric with spectroscopic variations in κ Dra (HD 109387) and 48 Lib (HD 142983).

2. Report on individual objects

Due to space limitations, we briefly report details on two objects only:

κ Dra (HD 109387): Slow $W(\mathrm{H}\alpha)$ weakening and associated increase of $\Delta V_{\mathrm{peaks}}(\mathrm{H}\alpha)$ from 125 to 200 km s^{-1}, this latter value being equal to $V\sin i$ given by Slettebak (1982), were seen between 1961 and 1979. They were linked with a slight decline of visual brightness (see also for overall variation, Hirata 1995). No substantial change was observed in D, which was always close to D_* value. From mid 1979 to 1984 there was substantial new development of emission lines with $W(\mathrm{H}\alpha)$ gradually increasing and $\Delta V_{\mathrm{peaks}}(\mathrm{H}\alpha)$ gradually decreasing down to 70 km s^{-1}, as the visual brightness which had firstly increased over 2 years afterwards slowly decreased similarly to D. The appearance of a dip in UBV around 1985 was interpreted by Juza et al. (1994) as due to screening of the central star by the vertical extent of the envelope. Note $D < D_*$ ($D_* = 0.292$ dex) at that epoch.

48 Lib (HD 142983):

Total Balmer discontinuity D is highly sensitive to shell and emission line strengths (equivalent widths and/or central depths). It has been observed that the higher D is, the stronger the equivalent width of shell (Balmer and metals) and emission lines (Hα and/or Hβ) is; however several times D maxima were some months behind shell line strength maxima. Lines are more sensitive than light to changes in the envelope.

Higher values of D are most often associated with lower values of the visual magnitude V and vice versa.

Long-term variations of D are similar in time-scales to V/R ratio of Hα and Hβ and to RV of shell lines, though these variations are evidently not phased. This observation can easily be explained by the lack of coincidence between shell strength maxima on the one hand and RV and V/R maxima on the other hand, this property being in common with other shell stars. In 48 Lib main and secondary D maxima and associated shell strength maxima occurred:

– in 1974.8 and 1982.5 at epochs of RV maxima or just after them,

– in 1965.5 and 1993.5 when $RV_{\mathrm{shell}} \sim RV_*$ (descending branch of RV curve) and $V/R(\mathrm{H}\alpha) \sim 1$.

Note that D secondary maxima in 1970.3 and 1974.8 occurred when $W(\mathrm{H}\beta)$ showed more or less pronounced maxima.

Conversely D is minimum when shell lines are weaker and brightness (V magnitude) is generally higher, as occurred:

– in 1968.3 near a RV minimum and when $V/R < 1$,

– in 1972.5, 1978.5 and 1988.2 when $RV_{\mathrm{shell}} \sim RV_*$ (ascending branch) and $V/R \sim 1$.

However a lack of simultaneous spectroscopic and photometric data (as in 1988.2) prevents a conclusive assertion.

Fluctuating $W(\mathrm{H}\alpha)$ decreased from 1970 to 1988 and then increased more rapidly and strongly up to 1993.3 as D reached higher values.

The higher $\Delta V_{\mathrm{peaks}}(\mathrm{H}\beta)$, the lower $W(\mathrm{H}\beta)$ in 1967 and 1973 near a D minimum.

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We tried to estimate lags of D maxima behind equivalent width maxima of shell or Balmer emission lines. We found:

– a 3-month shift between $W(\mathrm{H}\alpha)$ and D maxima in 1993,

– a 4-month shift between metallic shell strength and D maxima in 1965.

Finally we noted that the amplitude of the negative part of RV cycles, in reference to stellar radial velocity, is always larger than that of the positive part, indicative of episodic radial outflows. The larger the amplitude, the longer the cycle duration.

3. Summary comments

In this study we could not find precise relations but a number of tendencies which can be summed up as follows:

1. peak separation $\Delta\mathcal{V}_{\mathrm{peak}}$ of emission lines becomes smaller when line emission strengthens and vice versa;
2. brightness of stars is greater when line emission is stronger and D is smaller;
3. in shell phases D is minimum when RV $\sim$ RV$_*$ but in the ascending branch towards RV > 0 or near a RV minimum;
4. D is higher in SPh-A phases when RV > 0 are maximal and sometimes also when RV $\sim$ RV$_*$ but in the descending branch towards RV < 0;
5. RV < 0 when D is minimum and simultaneously $\Delta\mathcal{V}_{\mathrm{peak}}$ decreases as brightness increases;
6. brightness decreases as D increases and shell lines are stronger;
7. there is no correlation between long-term SPh and the $V/R(\mathrm{H}\alpha)$ variations.

From Huang's (1972) relation, which stipulates that $\Delta\mathcal{V}_{\mathrm{peak}}$ separation is an inverse function of the region extent, the above concluding remarks on the spectroscopic-SPh correlations suggest that:

1. there is an enlargement of the CE extent when line and continuum emission increase;
2. there seems to be a piling up phenomenon of the CE towards the central star when a shell event strengthens. As this phenomenon is accompanied by an increase of low excited transitions, there must be a simultaneous decrease of the CE temperature.

To the lack of SPh vs. V/R correlations we add that while the SPh variations are not periodic, the V/R are more or less cyclic. Also, the SPh variations are correlated with global line emission intensity while the V/R variations do not necessarily imply any global line emission intensity changes. It seems then that the global CE oscillations, which seem to provide a reliable explanation for V/R variations and/or appearance of steeple-type line profiles (Hanuschik et al. 1995, Okazaki 1996) are not relevant to trigger SPh variations.

4. Time lag between spectroscopic and SPh variations

In the foregoing comparisons of spectroscopic and SPh variations, we saw that there is a characteristic time lag $\Delta t \sim$ T months (T $\sim$ 3 to 10) between the preceding setting-up of emission in the line spectrum and that in the continuum. As opacity in the first hydrogen spectral lines can be higher than in the visible continuum, we may interpret this delay as the time a mass-loss event needs to increase sufficiently the emission measure of the CE zone to produce the observed continuum emission phenomenon. This can give us an estimate of the mass-loss rate involved in the phenomenon. For simplicity, let us assume an ellipsoidal CE with ellipticity E reduced to an effective disc-shaped CE with the same volume, so that its effective height is $h \sim (2/3)R_c$, where R_c is the radius of the continuum formation zone. Assuming the mass density in the CE has a distribution $\rho \sim \rho_a(R_*/R)^2$ (ρ_a is the mass density in the inner edge of the CE) the mass stored up is then given by:

$$\dot{M}\Delta t \simeq \frac{4}{3}\pi R_*^2 R_c E \rho_a \ln(R_c/R_*) \quad (1)$$

As in Be stars it is $\tau^V \ll \tau_e$, an estimate of the electron density in the inner edge of the continuum formation region can be derived from the condition $\tau_e \lesssim 1$. Using $E = 0.7$, $R_c \sim 2R_*$ and $T_{env} \simeq 0.8T_{eff}$ around a B2V type star, we derive:

$$\dot{M} \lesssim \frac{10^{-8}}{T} \quad M_\odot yr^{-1} \quad (2)$$

where the above estimates of T lead to rough mass-loss rates close to the upper limit of those derived for Be stars from the far-UV line spectrum. As it is difficult to reduce the above estimated mass-loss rate by an order of magnitude, the value obtained may reflect either events of strong mass-loss or movements of accumulated ejected mass around the star.

5. Conclusions

Increasing absorption in the second component of the Balmer discontinuity during SPh-A phases is related to increasing opacity of the CE and to a simultaneous decrease of its temperature which is seen by the enhancement of low ionized species. The existing spectroscopic data, more or less simultaneous with SPh data, support the assumption that SPh variations can be produced by episodic mass-loss events of $10^{-9}M_\odot$/year which are slightly stronger than those usually detected in the far UV.

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