PART I

OBSERVATIONS OF Be STARS

SPECTRA AND PHOTOMETRY OF Be STARS

(*Review Paper*)

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1. Introduction

My task is to review the spectroscopy and photometry of Be stars. In the wide range of topics this covers, I will naturally be biased by my own interests and knowledge. I hope however at least to mention all forms of observed behaviour within these limitations, but note that as we have specific sessions on energy distributions, rotation, observations at unusual wavelengths (i.e., not from 3500 to 6700 Å), and polarisation, I shall deal less thoroughly, if at all, with these topics. I shall also attempt to incorporate the results of the speakers who follow in this session, in order to save duplication of individual introductions and allow the later presentations to concentrate more on the relevant discussions. I shall deal with nine aspects of Be stars behaviour, under the headings below.

2. Rotation

The rotation of Be stars has been a subject of some controversy for many years. It is clear that the stars are, generally, rapid rotators and together with the evidence that the emission originates in an equatorial disk, led to the early suggestion that the stars lose mass by rotation at breakup velocity. This simple idea however meets with theoretical difficulties: unknown behaviour of a star under effective surface g of zero; lack of an ejection mechanism, outward transport of angular momentum. Collins has shown that line profiles do not correspond to breakup velocity of rotation and the need for a mass-loss mechanism has led to suggestions that the phenomenon may occur before the rotational velocity reaches breakup.

An investigation of the distribution of $v \sin i$ among Be stars by Stoeckley (1968) showed that current values of $v \sin i$ were clearly wrong and that allowance for gravity darkening effects produced a large correction. He was then able to fit the distribution with values of v corresponding to a half Gaussian centred on breakup, but still with half of the distribution lying below 475 km s^{-1}. However, his arguments do not consider the consequences of the peak lying at lower velocities. More recently, Massa (1975) has deduced a distribution (of about the same width) centred on $v = 350$ km s^{-1}, for all B stars which have shown emission. A significant point of his analysis is that *no* Be stars rotate at breakup velocity. It is clear that selection effects and heterogeneous estimates of $v \sin i$ can easily distort the picture, but these and other investigations point to the conclusion that Be stars probably do not need to rotate at breakup velocity. The distribution of Be stars with spectral type can be explained qualitatively by considering the emission line disk to be ejected by

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radiation pressure in the ultraviolet, in the low gravity equatorial regions, and some theoretical models (Marlborough and Zamir, 1975) have been constructed along these lines.

Further work on the rotational distribution has been done by Hardorp and Strittmatter (1970) and Bernacca (1970). These may be discussed in detail in the session on rotation, but for now it is sufficient to note that all these investigations indicate that while Be stars rotate rapidly, they are not necessarily at breakup velocity.

3. Special Spectral Characteristics

Here, as in most of this discussion, I restrict remarks to the usual photographic region of the spectrum, and leave discussion of other wavelengths to appropriate later sessions.

Because of their high rotation, lines in Be star spectra are often very broad and shallow and difficult to make measurements on. Radial velocity studies of useful accuracy are possible only on very low dispersion spectra with most measuring instruments. Wide scan oscilloscope devices, such as ARCTURUS at the Dominion Astrophysical Observatory, are necessary to make direct measurements on high quality spectra. Photoelectric scanners, TV cameras and other digital devices have also been used with variable success (see Figures 1 and 2).

Study of the lines present in some Be spectra has suggested that the stars correspond to a mixture of spectral types spreading over two or three subtypes. While classification procedures for such objects are not at all standard, and may be misleading, this does suggest that an appreciable temperature (and gravity) gradient may exist across the disk of the star. A quantitative estimate of these effects would be a valuable tool in deducing i and v_{rot}, and perhaps distinguishing between different gravity darkening laws.

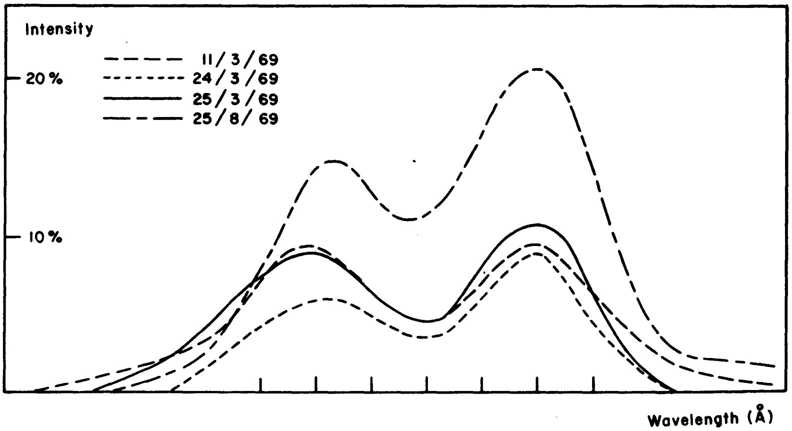

Fig. 1. Photoelectric scans of Hγ in γ Cas showing night-to-night changes and general increase in intensity over an interval of months.

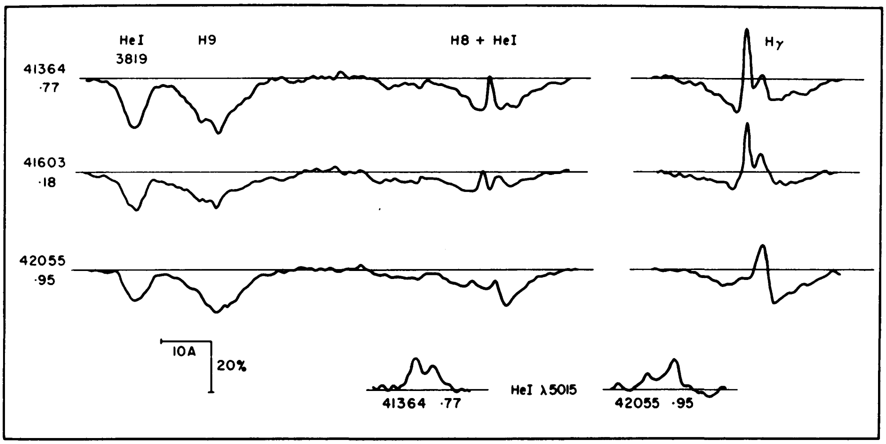

Fig. 2. Rectified spectrographic profiles from X Persei at different times. Julian Days and phases in possible 580 day orbital period are shown.

Another spectral peculiarity which is hard to detect is the appearance of emission in He I, and perhaps other lines. He I emission is seen in $\lambda\lambda$ 5875, 6678 in some Be stars, and occasionally at λ 5015 (Figure 2). It is rarely seen in other lines, although it has been suspected in κ Dra, and very probably is the cause of asymmetry in He I lines in X Per. Mg II λ 4481 emission peaks were also detected marginally in κ Dra (Hutchings *et al.*, 1971).

The peak separation in these cases is always larger than in the Balmer lines and presumably indicates formation in lower regions of the envelope where rotational velocity is higher, if angular momentum is conserved. The order in which the He I lines progressively show signs of emission is similar to that seen in the P Cygni supergiants and presumably indicates similar deviations from LTE level populations and transitions. In general, the lines which go most easily into emission, show lower peak separation.

A similar situation is seen in the Balmer lines. A progression is always found in peak separation, down the series (Figure 3). This is presumably because Hα is formed principally in the outer regions of the disk where it is optically thinnest and where rotational velocity is lowest (provided the rotation is not rigid-body). Down the Balmer series, separations increase as lines are formed closer to the photosphere. It is possible that such progressions can give us information from their slopes and zero points. One may expect these to depend on i, $\omega(H)$, $V(h)$, $\rho(h)$ and ρ_0, and if some of these are known or guessed from other information, careful measurement of the progression may be useful. I shall discuss later some predictions of simple geometrical models. Observationally, there is no clear correlation of the progression with i (as far as it is known), spectral type, or V/R ratio. It is noteworthy that the slope of HR 2142 is around the same for both shell and non-shell phases, although the separations are different. Also that the slope of X Per is much lower than any other I have seen. On the few stars where Balmer emission is seen far down the series, it appears that a maximum separation is reached at about H7 or H8, and this

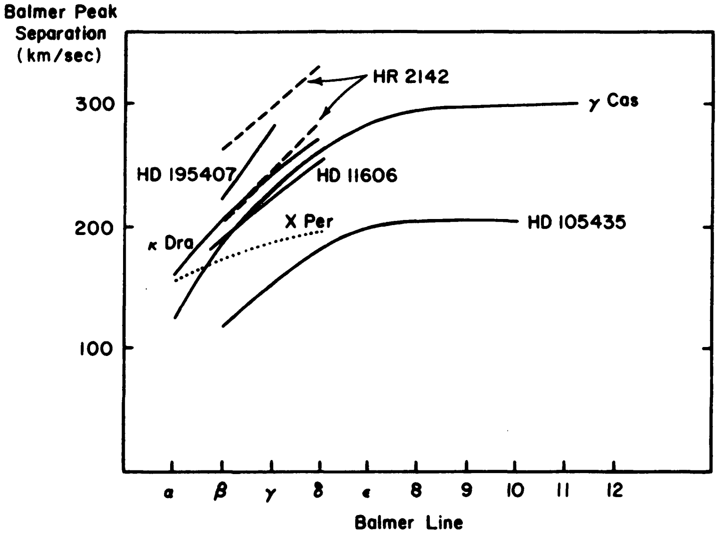

Fig. 3. Progression of Balmer peak separations in Be stars. Slope is similar for all spectral types and values of *i* represented, with exception of X Per.

presumably is a measure of the photospheric value of rotation. The conversion to *v* sin *i* is, of course, model dependent.

A further spectroscopic phenomenon is the width of the emission lines. In particular, the width of Hα is usually considerably greater (in velocity units) than Hβ. An investigation on a small sample of stars by Ringuelet-Kaswalder (1965) suggested that the *V*/*R* variables are qualitatively different from other Be and shell stars by (1) having a higher *W*(Hα)/ *W*(Hβ), (2) having no correlation of *W*(Hα) and *W*(Hβ) and (3) having main sequence luminosities rather than the one magnitude overluminosity of other Be stars. My feeling is that these results should be confirmed by work on a larger sample of stars, before attempting to explain them.

It is my general impression and experience that careful measurement of special spectral characteristics (line strengths, depths and widths, emission profiles and peak separations) can take us a long way towards defining or deciding between different models and parameters for Be stars, which in turn may lead towards a basic understanding of the Be phenomenon.

4. Periodicities in Emission Lines

Emission lines show *V*/*R* changes, velocity changes of edges and centre usually with characteristic times of hundreds to thousands of days. However, abrupt changes occur in the behaviour and it is rare to find more than two or three complete cycles before discontinuities occur (Figure 4). Some Be stars on the other hand show no such changes. There are also changes in the emission intensity which are generally unrelated and occur in time scales of tens to hundreds of days.

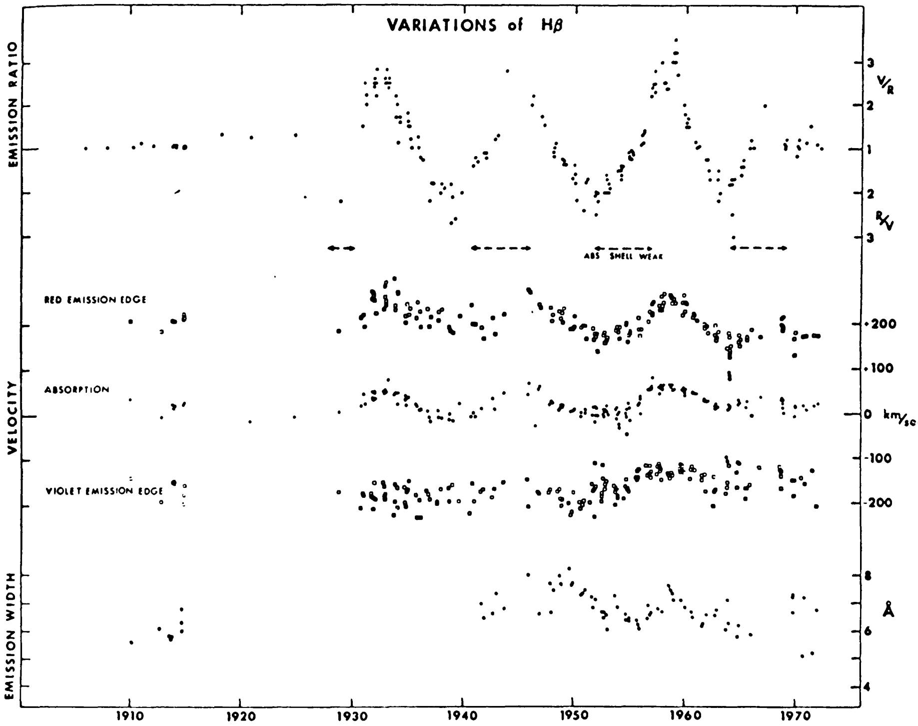

Fig. 4. Hβ line profile variations in β^1 Mon (by Cowley and Gugula, 1973), showing their discontinuous nature.

These changes may be ascribed to 3 possible causes. (1) Orbital binary motion of the Be star. This explains velocity changes, but only explains *V*/*R* changes if there is significant interaction between the stars, either in the form of tidal deformation of the line emitting region, or by emission from a gas stream between the stars, or by a phase dependent mass ejection mechanism. The lack of strict periodicity, discontinuities and periods of no change are serious problems in this explanation. (2) Changes are periods of mass ejection and mass accretion by the central star. These explain *V*/*R* changes and velocity changes if they are small. They cannot easily account for large velocity amplitudes as these would lead to regular P Cyg profiles. Also, the long periods involved make the accretion stage difficult to explain by fall-back, as mass will have left the system. Therefore a source of infalling matter, such as a mass-losing companion, is required. (3) Changes are caused by precession of an elliptical emission ring. This can explain all the observed phenomena, at least qualitatively. Discontinuities occur when fresh ejection forms a new ring. However, there are theoretical difficulties with this model which will presumably be discussed later. It is also difficult to explain emission intensity changes and very rapid changes in this model. Again, a possible way out is to involve streaming from a companion. These points are central ones for our discussion, but it seems at this point that we may well have to accept an explanation which embodies all of these effects in some way.

5. Rapid Variations

As detectors have improved, providing increased signal-to-noise and time resolution, it has become possible to study small scale spectral variations in a number of stars. Among the more spectacular results were those on Be star emission lines, where changes in times as short as one minute have been claimed (e.g. Bahng, 1971; Hutchings *et al.*, 1971) (Figure 5). It is often impossible to check such results by older tested methods so that there is sometimes an unknown instrumental contribution to such changes (monitoring seeing and guiding, with a slow scanner, signal averaging with a fast scanner, electronic instabilities and read-out noise in TV and solid state detectors). The general consensus is that many Be stars at some time show line profile and strength changes, which occur on time scales from ~1 h to 1 min (which is the present limit) and from more than 25% to a lower observational limit of 2–3%. The confidence with which such changes can be measured is a function of the equipment used and the extent of the changes themselves, so that at present little is known beyond the fact that they occur. No pattern of behaviour is apparent and no periodicities have been observed. It is not known what stars or types of star are more likely to show such changes, nor how frequently. Clearly, a full understanding of the processes will involve a very extensive observational program and probably sophisticated data reduction. Finally, it is not clear just how much we will gain from such a study.

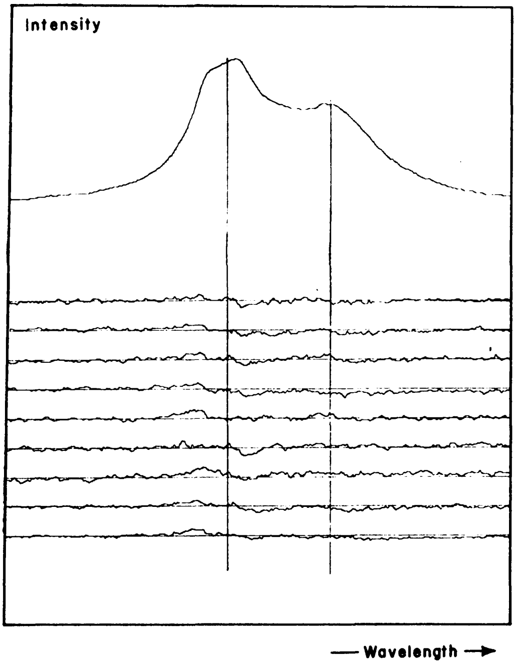

Fig. 5. Hβ in γ Cas. Isocon scans. Mean profile over 1 h and differences between this and sequential 6 min means.

The significance of such rapid changes may be clarified by simultaneous observation in different lines. This will show whether changes occur through the whole envelope or in a small part of it or whether different changes occur simultaneously in different parts. Some observations by Doazan suggest that changes occur in all lines at once, in time scales of 15–30 min, but others do not. These and shorter times scales imply disturbances which are very small, or which travel with speeds approaching *c*. If they occur simultaneously in different lines, they are more likely to be light-time effects. Perhaps a level pumping mechanism, and radiative de-excitation triggered by a flare, or pulse of radiation from the photosphere? Only more extensive, accurate and rapid monitoring will answer such questions. The only other datum at present is that variations seem to be most significant ($\Delta e/e$) in weaker emission lines, suggesting that disturbances occur preferentially in lower strata of the disk or envelope.

Looking at changes lasting longer than 1–2 h, we find that structure (e.g. extra absorptions) in emission sometimes occurs for these times. These may represent dynamic phenomena in a moving envelope: dispersal of density inhomogeneities, or rotation of the envelope. Recurrent, but discontinuous, periodicity in changes in the shape of emission in γ Cas (~0.7 days) has been attributed to the rotation of the envelope with variable, inhomogeneous emission intensity (Hutchings, 1970).

6. Photometry

The photometry of Be stars has been even more patchy and sporadic than spectroscopy. Here again, it has been found that variability exists on time scales from minutes to years and it is difficult to know (a) the true or undisturbed state of the star and (b) whether variations are in any way periodic.

In general, Be stars lie about one magnitude above the main sequence, and have an ultraviolet excess. These properties have been explained by various people as gravity darkening effects which move the star to later type and hence make them apparently bright for this type. However, it is not clear how much of the effect is a true evolutionary one and we will return to this question later. Once again, the study of mass-exchange in binaries may clarify this point considerably.

As far as the study of variability is concerned, most Be stars have been found to vary over some tenths of magnitudes – often more during shell activity. Feinstein (1968) found that 40% of a sample of southern Be stars showed variations of $\geq 0\overset{m}{.}06$ in *V* and 30% showed colour changes in $U-B$ of this size. Later work roughly confirmed these figures. Ferrer and Jaschek (1971) found a higher fraction to be variable: 60% variable in *V* and $B-V$ and 35% in $U-B$. Their data were taken over a longer time (17 years) and used a larger sample.

The long periods of variation and irregular non-periodic activity make it very hard to obtain 'light curves' for Be stars. An example is the star HD 187399 (which I have referred to before). A peculiar light curve is found which can be explained in its general shape by the distortion of the primary star to its Roche limit, in an elliptical orbit (Figure 6). This again should encourage us to investigate others (e.g., HR 2142), as any repeating photometric variation contains a lot of new information and light curve synthesis programs allow much of this information to be extracted.

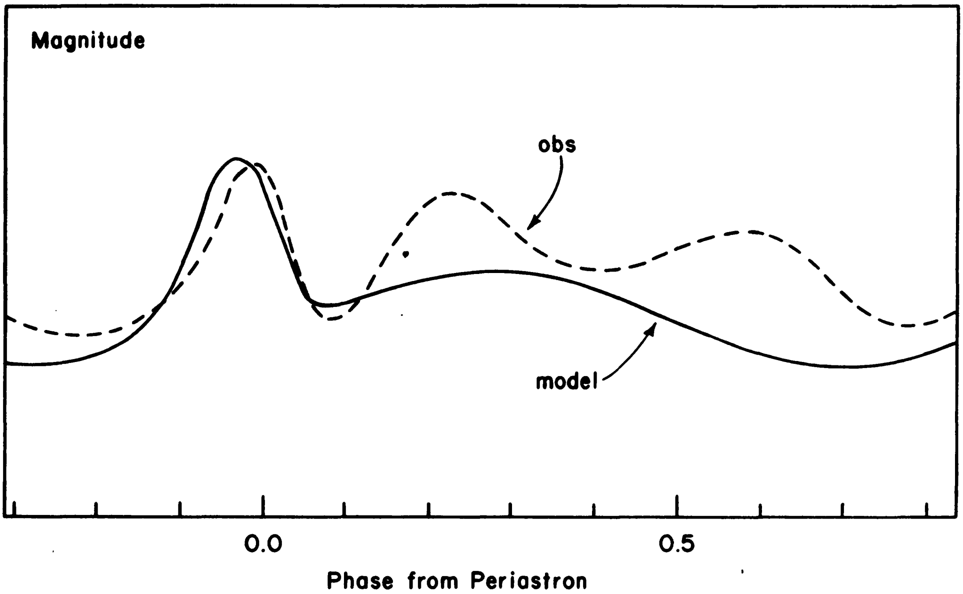

Fig. 6. Light curve of HD 187399 and calculated light variation (amplitude ≃ 0.1 mag.) of primary distorted to Roche limit at periastron passage. (Note that Harmanec (see p. 392) has alternative explanation.)

Looking to shorter time scales, little has been done. Plageman (private communication) made simultaneous rapid measurements of Hβ and continuum changes and found marginal activity with no definite periodicities. However, much more work of this nature needs to be done to be conclusive. Sanyal (private communication) has reported finding line variations in the Balmer and He I lines in HD 57219, but no activity in the nearby continuum, using special filters.

7. Shell Spectra

The distinction between Be and shell stars has often been a confusing one to me, and I can find no clearly defined criteria in the literature. I suspect that the confusion is not restricted only to myself and that the terms are used somewhat loosely by a number of people. There are shell stars, shell phases, and shell spectra. What I hope to discuss briefly is the spectrum seen when sufficient matter exists around a star to affect its spectrum in a way which is different from the Be phenomena discussed so far. This implies in the context of Be stars that at times or in some stars, either sufficient mass is ejected by a non-continuous force to form a detached envelope, or such an envelope is formed by some unusual accretion event. A shell may however be simply a very extended Be star envelope. Spectroscopically a shell is seen by the existence of sharp and unusually deep absorption lines of hydrogen, He I and of metals such as Si II, Fe II, Ti II. The usual emission lines are often enhanced. The absorptions may be asymmetrical, and show different radial velocities, particularly as a Balmer progression. Velocities may be positive or negative with respect to the stellar velocity and may change over periods of weeks, months, or years. The shell lines show, in fact, most of the behaviour characteristics of Be spectral lines, and the same types of explanations may be put forward to account for them. It is clear from the line depths that densities are higher and radiation more dilute than in normal Be envelopes. The velocity gradients have been interpreted as due to ballistic and collisional slow-down and/or increase in density with height by interstellar material, or of accelerating infall. This distinguishes shells from steady state envelopes in which outward velocities may accelerate under a constant driving force. Thus, the denser regions may lie on the outside of the shell, and evidence for this is found in the velocity progressions, line asymmetries and widths of the shell absorptions, between ions and along the Balmer series.

In particular the shell phase of Pleione, which lasted several years, has been analysed by several workers. Limber (1969) showed that the observed velocity of the higher Balmer lines and strengths may be reproduced by a model with slowly increasing mass ejection and a sharp cutoff, but with an increasing velocity with height. Malborough and Gredley (1972) however showed that this model was unable to reproduce the Balmer progression in the later shell stages. They conclude that it is not clear that the basic model is right, although some way of incorporating emission in the velocity field of the shell may improve the picture. The alternative model they suggest is that of two line forming regions with different Balmer decrements and velocities, but no one has explored this seriously yet.

The steady shell of 1 Del has been modelled by Marlborough and Cowley (1974). A good fit to Hα was obtained by a model again with outward acceleration ($\mathrm{d}V/\mathrm{d}w > 0$), and extending to $\geq 30\ R^*$. (A different approach by Kitchin (1973) led to similar conclusions about the extent of the Be envelopes in general, even without shell spectra, but his analysis seems to depend on lines formed in the outer envelopes.)

8. Binary Be Stars

As there is a session devoted to the question of whether Be stars are all binaries or not, I do not intend to discuss this hypothesis. However, it is certainly true that several Be stars are known to be binaries, and their behaviour is determined by this circumstance. I shall therefore discuss briefly a few remarkable Be binaries (Table I).

TABLE I

Some Be star binaries

Name	Period	K (km s^{-1})	V_0 (km s^{-1})	e	$f(m)$
187399	28 d	105	−20	0.39	2.6
4 Her	46 d	11	−15	0.38	0.006
173219	58 d	124?	25	0.15	11.4
HR 2142	81 d	20?			
88 Her	87 d	10	−12	0.16	0.008
AX Mon	232 d	52	6	0.02	3.0
X Per	580 d	66	−50	0	18
β^1 Mon	12.5 y	30?		0	13

HR 2142 was discovered by Peters (1972) to have a periodic shell phase, during which positively displaced absorptions were seen in Balmer and He I lines. These repeat every 81 days, and thus suggest a binary origin. Radial velocities of the broad primary absorption suggest an orbital ($e > 0$) motion, which, however, needs to be confirmed. Two explanations are possible here, which only a good orbit can resolve: mass-ejection at periastron by the primary, or mass-accretion seen along the gas-stream. The present velocities make either possible.

This again calls to mind the binary HD 187399 (Hutchings and Redman, 1973a) which shows a strong shell effect at periastron in an $e \sim 0.4$ orbit. There seems to be a good case for roche lobe overflow in this system, so that it may be expected in others. The star is not a Be star in the sense we mean at this meeting so I will not discuss it further than this.

HD 173219 is a Be star with a 55 day orbit (Hutchings and Redman, 1973b), with several peculiarities. Chief of these is that the value of K is very different for different lines, so that the mass function is somewhat uncertain. Also, there is no clear explanation for the effect (either tidal or heating) and the secondary is mysteriously unseen.

A good case exists for the binary nature of 4 Her (Harmanec *et al.*, 1973), with a period of 46 days and $e \sim 0.4$, on the basis of velocity variations alone, and the system will be discussed further by Dr Harmanec at this meeting. He also has evidence for an 87 day period, $e = 0.16$ orbit for 88 Her. All these binaries are fairly well separated and presumably have evolved beyond core hydrogen exhaustion before any mass exchange. This *may* be significant in explaining the origin of the Be phenomenon.

Finally I would like to mention X Persei. This star has been suggested (Hutchings *et al.*, 1975) as the optical counterpart to a weak X-ray source (3U0352+30). Radial velocities of the broad absorptions show periodic variations of large amplitude and period 580 days, implying the presence of a very massive unseen secondary. Emission line velocities are antiphased and of much lower velocity, and the Balmer decrement and peak separation progression much lower than normal. It is possible that *some* emission arises from a high density region near the secondary, accounting for these differences, and that this object is a massive collapsed star. If this is so, it may require that the primary is losing mass to and not gaining it from such a companion.

Few other Be stars show strictly periodic spectral changes or light changes. It has been suggested that some of the cyclic changes represent binary motions (e.g., β^1 Mon by Cowley and Gugula, 1973) which are not always seen for some reason. No Be star is known to show eclipses, again presumably because of the high separations in these systems.

Any further points on Be binaries should probably await the discussion reserved for this topic. It is clear that the detection and study of Be binaries is difficult and there may be considerable complications. An attempt has been made at the Dominion Astrophysical Observatory (Gower, private communication) to detect the presence of faint late type companions to Be stars, by obtaining very high signal-to-noise television scans at $\sim \lambda 6400$ Å, where there are many late type spectral lines. A numerical convolution of the spectra with standard late type star scans is very sensitive to the presence of a blended late type spectrum in the data. Preliminary results for upper limits to a late type companion are as follows: γ Cas (0.01), κ Dra, 4 Her, 48 Lib (0.007). 4 Her is a known binary whose probable late type contribution is 0.005, so we need to increase the accuracy of the observations to make it sufficiently sensitive to be useful.

9. Statistics and Evolution

As the Be phenomenon is variable in its strength, estimates of the number of Be stars are likely to be underestimates. The numbers found range from the ~8% found in clusters by Schild to ~20% for all Be stars by Massa. The distribution by spectral type is highest for early B, lower for late B, and falls off beyond B9 and perhaps earlier than B0. It is possible that the Be phenomenon depends on the existence of radiative pressure to support a disk-like envelope. The effect falls with increasing spectral type and at very early types it may be strong enough to blow away such a disk. These arguments favour the single star hypothesis, but can be incorporated into accretion as well.

Further statistics and surveys relevant to this question will be reported by Drs Hubert and Bidelman at this meeting. The evolutionary stage of Be stars is perhaps one of the important points for discussion here. I have mentioned the work of Hardorp and Strittmatter and others who claim that gravity darkening and aspect effects will move Be stars from the ZAMS to their observed positions. Schild (1966) has claimed that even with these effects the stars (and especially the Bex stars) lie on the hook of the evolutionary track. Model atmosphere analysis to be reported by Peters at this meeting has suggested log g values of 3.5–4.0 which also suggest that some lie off the ZAMS. Finally, the question of mass-exchange in binaries is one tied in with evolutionary radius changes. Most models suggested are evolved off the ZAMS to beyond hydrogen-core burning.

Schild (1966) has introduced the sub-class of Be stars known as 'extreme'. These are characterised by being basically similar and stable, showing stronger emission and having weaker absorption lines. They are also slightly redder than 'normal' Be stars. More recently, in a study of Be stars in clusters, Schild and Romanishin (1976) have claimed at this meeting that Hα emission and Bex characteristics are found most strongly at the end of core H burning, supporting the claim that Bex stars are a class of Be stars whose mass loss is caused or enhanced by core contraction. These claims are difficult to make convincingly and the idea is regarded as controversial by some. I hope Dr Schild will present his arguments and that we may have some profitable discussions in the next session.

10. Expanding Models

Finally, I should like to discuss some geometrical models for Be envelopes in the sense that they apply directly to observational quantities. Dr Marlborough will discuss the details and theoretical justification of these and other models in due course. The class of models I want to consider are extended equatorial disks in which angular momentum/unit mass is conserved and in which line emission and absorption are simply proportional to the density. The density falls in a way necessary to preserve continuity. The free parameters to be explored are thus largely geometrical: velocity of outflow (constant with height, as small gradients produce very similar results), radial extent, spread out of orbital plane, and inclination of line of sight. It is of interest in comparing models with observation to know what quantities the observed features are sensitive to. Model profiles were computed in a grid, using three geometries: (1) disk extending 10% from equatorial plane, with maximum thickness 1 R_* and (2) disk 30° from plane, extending 1.5 R_* (3) disk covers whole star, but extends only to 1.3 R_* away from equator. The results are shown in Figures 7 and 8 and may be summarised as follows:

(1) R/V is a function of expansion velocity and is about the same for all models. The increase in R/V with expansion is fastest for i small.

(2) The peak separation *varies* with expansion velocity similarly for all models, but is larger for the thicker disk. The separation increases by ~15% when expansion goes from 0 to 60 km s^{-1}, for all i.

(3) The emission EW is the same for all i, unless electron scattering is present, or absorption in the line of sight.

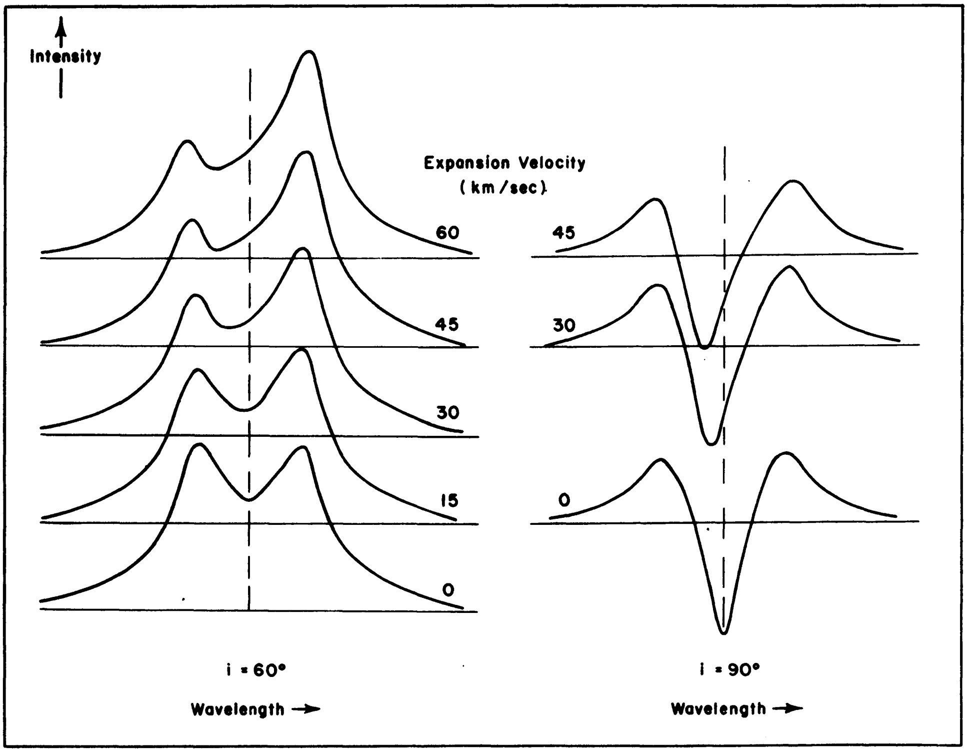

Fig. 7. Calculated Balmer line profiles for equatorial expanding envelope (±10°, maximum thickness 1 R_*, extending to 5 R_*, conservation of angular momentum).

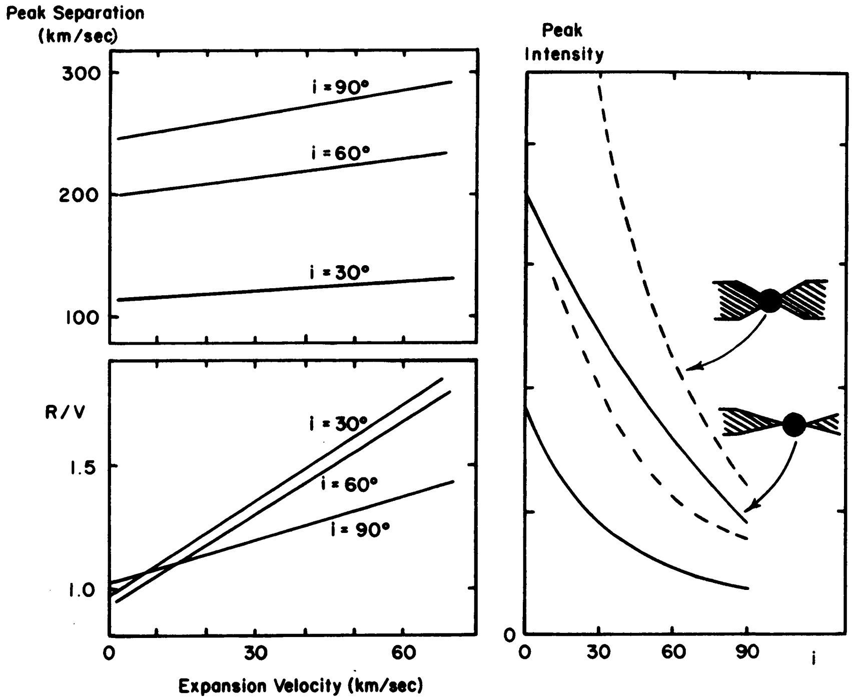

Fig. 8. General behaviour of calculated double peaked emission lines for expanding envelopes.

(4) The peak intensity varies with i similarly for all models. At $i = 0$ it is two times that at 30°, four times that at 90°.

(5) The separation varies with radial extent of the envelope similarly for all i, and less for the thick disks.

(6) The central dip is less marked for thick disks (aside from absorption in the line of sight). Expansion gives a shallower minimum, and so does an increase in i (aside from absorption).

The properties of a model can be deduced from such a grid and compared with a grid of observed stars. Naturally other data and considerations must be used to decide on the validity of such models, unless complete incompatibility with observation eliminates them entirely. It seems that many features of Be star profiles are explainable in terms of such models and we now need a grid of good observations of different stars to test them. In particular, I hope we can help to use the information contained in V/R ratios, peak separations and emission line widths to test such models and eventually lead to a better understanding of the mechanisms of the Be star envelopes.

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DISCUSSION

Plavec: Can we stop for a moment to discuss this problem of V/R variation? I would like to point out that first of all, it would be nice to know whether the periodicity of the phenomenon is typically years. It is possible that it is so, but I don't know if the observational evidence is really very convincing, because when you look at the old observations, as made by Curtiss and McLaughlin, what strikes you is that the observations were made regularly each year once or twice in the same season. This type of observation made once a year certainly fails to detect periodicities of the order of decades or months. I wonder whether we are really sure that the typical periodicity is years?

Hutchings: In *some* cases (e.g., X Per or β^1 Mon) it seems clear that the variation with 'periods' of some years is definitely present, as coverage on such a time base is good. In other cases, of course, Plavec's remarks are very true, and there may be shorter periodicities present which have been missed.

Peters: HR 2142 was on McLaughlin's observing list for about 30 years, and he missed the periodic shell activity. He also missed the periodicity in V/R in Hβ because he only obtained one plate per year. Since the period is 81 days and the duration of the shell phase is 7 days, at least 10 plates per year would have been required to find the periodic shell structure.

Snow: I question the reality of the ultraviolet excesses often attributed to Be stars, because I believe that the ultraviolet extinction is often over-estimated. Reddening due to excess infrared emission can lead one to expect far more ultraviolet extinction than is actually present; thus the appearance of an apparent ultraviolet excess can be due to an over-estimate of the extinction, rather than to a true excess of flux in ultraviolet wavelengths. An example of this is χ Oph, whose $B-V$ color implies $E(B-V)\simeq 0\overset{m}{.}6$, but which can be shown to have a true interstellar extinction corresponding to a color excess of $E(B-V)\simeq 0\overset{m}{.}35$ (Snow, *Astrophys. J.* **198**, 361, 1975). *Copernicus* data on a few bright Be stars show that in most cases the flux in the ultraviolet compared to that in the V bandpass matches the distribution in normal stars of similar MK class, if an intrinsic reddening of the order $0\overset{m}{.}2$ in $B-V$ can be assumed for the Be star.

Plavec: I would like to point out two facts. You just mentioned that the envelope extends rather far from the star: 30 or so stellar radii which might be 100 solar radii from the surface of the star. On the other hand, there have been several articles written, for example, by Boyarchuk where he derives that the emission and absorption features are formed within two or three stellar radii, which is inconsistent with what was found by Marlborough. Boyarchuk's data are derived from the assumption that the angular momentum is conserved in outer layers so he measures the width of the individual lines and derives the distances. It seems to me that the results based on radiation transfer in the lines indicate very clearly that the assumption is wrong. Because of this discrepancy, I think one has to conclude that it is not true that the angular momentum is preserved in the envelope. And another point: we all are used to the idea that shell stars are Be stars at which we look edge-on, so that the flat disc as seen in the equatorial plane is seen at great geometrical depth. But we should remember, for example, the case of 17 Lep, where Anne Cowley found that the inclination is really not near 90°, but something like 20° or 30°. So we are looking at a system very far from the equatorial plane, yet there is plenty of material there for we see strong shell lines. Therefore in some cases, at least, we must accept the fact that the system is surrounded by a cloud which is certainly extended very far away from the central plane.

Doazan: I think that almost all the lines in X Per are in emission. How did you measure the radial velocities of the absorption lines?

Hutchings: We measured the broad underlying absorption in the Balmer lines from about H8 to H12 or so, using our wide scan oscilloscope machine. In these lines the emission is present only weakly in the center and on good (usually IIIa-J) plates we could get good agreement between individual lines velocities.

Henize: If I may comment on distribution with spectral type, the data from my southern Hα survey (now in press) may be of interest. It was something of a surprise to find that peak frequency among 1232 stars with spectral types (nearly all are HD types) occurred at spectral type B8 (207 stars) in contrast to the classical data by Merrill which showed an apparent peak at B3 (my data show only 110 stars of this type). Most of my stars lie between $m_v = 8.0$ and 10.0 and therefore are somewhat affected by the systematic misclassification of B8 and B9 stars in the HD and HDE catalogues. This effect shifts the peak to class B6 or B7 on the MK system but it is very difficult to completely explain the peak away on this basis. Rather, it seems likely that the B8, 9 peak is explained partly by the greater proportion of B8, 9 stars among the fainter stars caused by interstellar absorption and partly to my ability to observe weaker emission lines than could be observed by the early surveys. Since the B8, 9 stars show considerably weaker emission than the B0–B2 stars, it should be expected that my survey will show a greater proportion of B8, 9 stars. That the emission-line stars with HD spectral class B8 are significantly later than those with HD spectral class B0–B2 is borne out both by their distribution in galactic latitude and by the differing distributions of emission-line intensity.

Hutchings: It is important to eliminate supergiants and selection effects in discussing the distribution of rotational Be stars. Schild and Massa have attended to these points carefully.

Cowley: With regard to Henize's comments, if HD spectral types were used, N. Houk finds for the faint stars that many early B's are classified as later B's because of the strength of the interstellar K line, which Miss Cannon did not recognize as non-stellar. It would be better to use the new types of Houk before this statistical result is accepted. (**Note added in proof:** Analysis of the frequency vs spectral type of the Be stars in the *Michigan Catalogue of Revised HD Spectral Types* shows the same frequency distribution for bright and faint stars.)

Heap: I have a comment concerning the spectral type of ζ Tau. I found that the ultraviolet line spectrum of the star suggested the atmospheric parameters, $T_{\mathrm{eff}} = 27\,500$ K, $\log g = 4.0$. This value of T_{eff} is a good 10 000° higher than estimates based on visual studies, e.g., the spectral type B4 IIIp (Lesh, 1968), and the observed Balmer jump (Schild *et al.*, 1971). After studying some visual data, I found that there is no real discrepancy between the effective temperatures indicated by the visual and ultraviolet regions of the spectrum: the lines which suggested to Lesh a late spectral type (e.g., strong Mg II 4481) are really *shell* lines, and the strong Balmer jump observed by Schild *et al.* is due to *shell* absorption. Hence, both the visual and ultraviolet spectrum of ζ Tau indicate a high effective temperature – around 27 000°, if you use Mihalas' non line-blanketed models.