III. SPECTROSCOPY

SPECTROSCOPIC OBSERVATIONS OF Be STARS IN THE PHOTOGRAPHIC AND VISUAL REGIONS

(Review Paper)

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1. INTRODUCTION

The term "Be star" has been used at times to describe classes of objects which are physically rather different from one another. While it could include early-type supergiant stars with Hα emission, early-type pre-main sequence nebular variables, or quasi-planetary nebulae like MWC 349, I will limit this review paper to a discussion of the "classical" Be stars. These are defined as stars of luminosity classes III to V, usually rapid rotators, which show normal B-type spectra with superposed Balmer (and sometimes Fe II) emission. Included also, however, will be the Oe stars and the A-type shell stars, which seem to represent extensions of the classical Be phenomenon to higher and lower temperatures, respectively.

The proceedings of IAU Symposium No. 70 on Be and Shell Stars (D. Reidel Pub. Co., Dordrecht, Holland, 1976) contain papers and references to Be-star research done up to 1975. A later review paper on Be stars (Slettebak, 1979) includes more recent references plus some historical comments. Also, Hubert-Delplace (1979) has written an excellent review paper on spectroscopic studies in the visible. I should like to limit my discussion in this paper to work done since the 1975 IAU Symposium and omit also much of the historical discussion in my aforementioned review paper.

Finally, I would like to make the usual disclaimer with regard to completeness which all reviewers must feel. Research in Be-star spectroscopy has been very active in recent years and I realize that my own particular interests could well have introduced a bias causing me to overlook significant work done in this field. We can all agree that Be star researchers represent an unusually fine group of human beings -- since I do not want to lose any of you as friends, I hope that you will regard any omissions in my paper as entirely unintentional.

M. Jaschek and H.-G. Groth (eds.), Be Stars, 109–124.

2. SURVEYS AND ATLASES

Large numbers of new Be stars continue to be reported each year, mostly as a result of surveys for Hα emission-line objects. Recent work includes that of Arkhipova et al. (1976), Coyne et al. (1978), Doazan et al. (1977), Dolidze et al. (1977), Gomez and Mendoza (1976), Henize (1976), Irvine and Irvine (1979), Kucewicz (1980), MacConnell (1981), Martinez et al. (1980), Sanduleak and Bidelman (1980), Stephenson and Sanduleak (1977), and Vega et al. (1980). It seems likely that new Be stars, including relatively bright objects, will continue to be discovered in future years, for at least two reasons: (1) Many Be stars show spectrum variability over long time periods, reverting to the appearance of normal B-type stars between shell episodes. An Hα survey at any given time would therefore miss a certain fraction of potential Be candidates. (2) Hα emission is often weak and narrow, requiring relatively high-dispersion spectra for detection. Objective-prism spectroscopy would be likely to miss such objects.

A beautiful and useful atlas of Be-star spectra has been published by Hubert-Delplace and Hubert (1979). The atlas includes 51 plates of photographic spectra of 35 Be stars, showing spectrum changes over 10-20 years for most of the stars. A description of spectrum changes for 148 stars since about 1953 is also included.

3. THE UNDERLYING STARS

Spectral classification of the stars underlying the Be shells is very difficult because of the great line broadening typically shown by these objects, as well as the disturbing effects of line emission in their spectra. Yet it is important to know the distribution of spectral types and, especially, luminosities, of the Be stars if we are to understand their relationship to normal stars and how they evolve. Programs of spectral classification of Be stars are underway at several observatories.

Divan (1979) has developed a quantitative system of spectral classification of Be stars from low-dispersion spectra, involving measurements around the Balmer discontinuity. Of special interest is the fact that two Balmer jumps are observed in some Be stars, one from the underlying star and one from the shell.

Jaschek et al. (1980) have developed a classification scheme for Be stars based upon the visual inspection of several thousand spectrograms collected at the Meudon Observatory between 1953 and 1976 of 140 northern Be stars brighter than about magnitude 7 (the same plate material that was used for the aforementioned atlas of Be-star spectra). They derive MK spectral types and then establish five groups of Be stars, using spectrum characteristics and the time scale of variations as parameters, and suggest that predictions of the future behavior of a given star can be made once it is assigned to a particular group.

Spectral classification of southern Be stars has been done or is in process at several observatories. Garrison et al. (1977) classified 148 Be stars among 1113 OB stars brighter than the 10th magnitude observed at the Cerro Tololo Inter-American Observatory. Jaschek and Jaschek (1979) are observing and classifying southern Be stars brighter than magnitude 8.0 with dispersion 20 Å/mm at the European Southern Observatory.

I have recently completed the spectral classification (Slettebak, 1981) of all the known northern and southern Be stars brighter than magnitude 6.0. Greatly-widened, fine-grain (IIIa-J emulsion) spectrograms of dispersion 40 Å/mm were obtained at the Lowell Observatory in Flagstaff, Arizona and at the Cerro Tololo Inter-American Observatory in Chile, in order to permit accurate spectral classification plus visual estimates of line broadening for rotational velocity determinations. Preliminary results indicate that of the 168 stars with spectral types in the range B0 to A0, there are about twice as many B0-5 as B6-A0 emission-line stars. The number of stars estimated to be more luminous than class V was greater than the number of main-sequence stars for both the B0-5 and B6-A0 groups. This confirms earlier work on Be stars in galactic clusters and binary systems which shows these objects to be somewhat above the main sequence, on the average.

Axial rotation of Be stars will be discussed at greater length in the review paper by Dr. Harmanec, but its importance in the Be phenomenom is certainly one thing we can all agree upon. As a class, Be stars are the most rapidly rotating stars known (excepting degenerate stars, of course), and the presence of shells around them must be related in some way to their rapid rotation. My spectrograms of the brighter Be stars (Slettebak, 1981) confirm their rapid rotation but show very little difference in mean rotational velocities between the early-type and late-type Be stars, on the one hand, and between the main-sequence and subgiant-giant Be stars in both groups, on the other.

While we puzzle at this Symposium as to what Be stars are and how they throw off their shells, we should remember that the Be phenomenon apparently extends to both earlier and later spectral types than B. Our theories and ideas should encompass also the Oe and the A-type shell stars. Both are also characterized by rapid rotation, have luminosities in the main-sequence to giant band, and show shell features (though not necessarily emission lines) in their spectra. Frost and Conti (1976) estimate that 14 percent of O-type stars have exhibited the Oe phenomenon (including Balmer emission) at some time. This is somewhat less than the approximately 20 percent estimated for the early B-type stars (Slettebak, 1979). The fraction falls off toward the B stars of later type, and is quite uncertain for the A-type stars. Although only a few (e.g., 17 Lep, 14 Com) were known in Struve's time, their number has increased significantly since then, thanks to the work of Abt and Moyd (1973) and others. Recent papers, which include references to the earlier work, include Andersen and Nordström (1977), Clayton and Marlborough (1980), Dominy and Smith (1977), and Slettebak (1979).

4. THE SHELLS

I should like to make some general remarks about the shells surrounding Be stars at this point; recent work on individual objects will be discussed in Section 6 of this paper.

Struve's (1931) rotational model for Be stars suggested a rapidly-rotating underlying star surrounded by an equatorial ring or shell which gives rise to the emission lines. In addition to the Balmer line (and sometimes Fe II) emission from the shell as a whole, that portion of the shell which is seen projected across the photosphere of the underlying star gives rise to absorption lines which are relatively sharp as compared with the broad absorption lines from the rapidly-rotating underlying star.

Be stars which show such narrow absorption lines in their spectra have been called "shell stars". This is somewhat misleading since all Be stars can properly be called shell stars insofar as their emission arises from some sort of surrounding shell. Be stars with the most pronounced absorption-line shell spectra always show considerable broadening of the absorption lines from the underlying star, however, implying that we are viewing them nearly equatorially. It is these objects (e.g., Pleione, 48 Lib, etc.) which historically have been called "shell stars".

The absorption-line spectra from Be shells may look very different from star to star. The hottest Be shells show lines arising from metastable energy states of He I (e.g. λ 3889 and 3965) in addition to the sharp central absorption cores in the Balmer series. Somewhat cooler shells (generally surrounding underlying stars in the spectral-type range B2-9) also show sharp Balmer core absorption plus a metallic-line spectrum (Fe II, Ti II, Ni II, Cr II, etc.) which resembles somewhat the spectrum of the A2 supergiant α Cyg. Typical metallic lines which are usually strong in such shell spectra include Fe II 4179, 4233, 4549, and 4584, all of which arise from metastable levels 2.6 to 2.8 eV above the ground state. The coolest shells are found surrounding rapidly-rotating stars of spectral-type A. These generally show neither Balmer emission nor Balmer absorption cores (an exception is 17 Lep which, however, is atypical in having an M-type companion plus an expanding shell). Shells surrounding A-type stars may show sharp absorption cores in the Ca II H and K lines (which arise from the ground state) and sharp lines of Ti II at 3685, 3759, and 3761 Å. The latter have lower levels which are metastable and only about 0.6 eV above the ground state. Clearly these shells are now so cool that very little hydrogen nor Fe II is to be found in excited energy levels.

Physical parameters for Be shells as determined by various techniques were summarized in my review article (Slettebak, 1979) as of the literature of 1977-78. Much important work has been done since and we will hear about it during this Symposium. Ultraviolet observations have been especially important in emphasizing the role of mass loss, particularly for the Be stars of early type. There are still problems associated with the mechanism by which Be shells are produced, however. The discontinuous nature of shell ejection and shell dissipation (even though slow) suggests that something in addition to stellar winds must be operating. Even more serious problems arise in trying to explain shells around the later B-type stars (e.g., Pleione) and, especially, around A-type stars, since these do not seem to have sufficiently strong stellar winds to move matter out into the shells. Is it possible that magnetic fields play some role here (as well as in the hotter Be stars), as was suggested by Limber (1974, 1976) and by Saito (1974)? Recent work by Clayton and Marlborough (1980) on polarization in A-type shell stars places an upper limit of about 300 gauss on any longitudinal fields which may exist undetected. Could smaller fields be effective in Be and A-shell production?

5. VARIABILITY

Variability is an inherent part of the Be phenomenon. I would like to make a few general remarks and then discuss individual stars in the next section of this paper. This discussion is restricted to variability in Be spectra in the photographic and visual regions. A great deal of work has been done on photometric and polarimetric variability as well as variability in the X-ray, ultraviolet, and infrared spectral regions of Be spectra, which will be discussed in other papers during this Symposium.

Be spectra appear to vary on several time scales. The variations are sometimes periodic or quasi-periodic but more often irregular. Be shells have been observed to come and go in intervals of a decade or two (e.g., γ Cas and Pleione), leaving a fairly normal-looking, rapidly-rotating B-type star between shell episodes. A decade is also the approximate time interval between quasi-periodic spectrum and radial velocity changes for the well-studied Be stars 48 Lib and ζ Tau. Quasi-periodic changes in V/R (the ratio of the violet to the red emission components in the Balmer lines of Be spectra) have been observed in many Be stars, again on time scales of the order of a decade or so. Many examples of Be star variability may be found in the aforementioned Hubert-Delplace and Hubert (1979) atlas. Additional references to earlier work are in my review paper (Slettebak, 1979) -- more recent work will be discussed in the next section.

Spectroscopic observations of Be stars also suggest variability over shorter time scales. Changes in time periods of months seem well established; references to the earlier work may be found in Slettebak and Reynolds (1978), whereas recent papers describing such variations include those by Doazan et al. (1980), Elias et al. (1978), Hirata and Kogure (1979), Metz and Pöllitsch (1979), and Reynolds and Slettebak (1980). Additional papers will be discussed in the next section.

Variations in Be Spectra on time scales of days, hours, and even minutes have also been reported, but here there is rather conflicting evidence. Such variability is generally irregular, which makes it difficult to separate real spectrum changes from random variations. Clarke and Wyllie (1977), and Lacy (1977), in particular, have cautioned against interpreting all observed changes as real. Again, references to the earlier work may be found in Slettebak and Reynolds (1978). Papers written since IAU Symposium No. 70 in support of rapid spectroscopic changes include those by Aydin and Faraggiana (1978), Baliunas and Guinan (1976), Bijaoui and Doazan (1979), Cowley and Houk (1976), Dachs et al. (1977), Fraquelli (1979), Gulliver and Bolton (1978), Gulliver et al. (1980), Harmanec et al. (1977), Mamatkazina (1978), Schoembs and Spannagl (1976), Slettebak and Snow (1978), and Vojkhanskaya (1976). On the other hand, Kitchin (1976), Luud (1978), and Reynolds and Slettebak (1980) have searched for rapid changes in Be spectra, without success. Such irregular changes, if confirmed, would give us information about turbulence and physical conditions in the Be shells.

Not all observed rapid changes in Be spectra are irregular, of course. Baade (1979), for example, reports changes in the spectrum of ω CMa with period 1.36 days, which he attributes to non-radial pulsations in that star. Short period, interacting-binary Be stars or rotation of an active area on the surface of a single Be star could also produce changes in their spectra on time scales of hours or days.

One method of guarding against the instrumental or terrestrial atmospheric effects which could be confused with real changes in Be spectra is to observe these objects simultaneously with independent telescopes and recording systems. This has been done by Haefner et al. (1975), Metz and Pöllitsch (1979) Reynolds and Slettebak (1980), and Slettebak and Snow (1978), for example, but more observations would be desirable.

6. RECENT WORK ON SOME INDIVIDUAL Be STARS

Pleione. One of the most studied of the Be stars, Pleione continues to be entertaining. The star entered a new shell phase in 1972 and the shell has developed during the 1970's. In a series of papers, Hirata and Kogure (1976, 1977, 1978) and Higurashi and Hirata (1978) have studied Pleione's latest shell phase. They report a gradual development of the shell from 1972 to 1976, the envelope concentrated toward the equatorial plane and continuing its slow expansion in that plane as well as in the vertical direction, with a nearly constant mass-loss rate of 4×10^{-11} $M_{\odot}$ yr.$^{-1}$. They suggest that the shell consisted of a relatively compact, dense and cool region concentrated toward the equatorial plane and a hotter extended region, with mean excitation temperature 9000-10,000 °K in 1973-1976. Gulliver (1977) studied the spectrum variations of Pleione from 1938 to 1975 and reported that his observational material rules out the elliptical ring and binary models for Pleione, whereas good agreement was found between the stellar wind model and the observed variations, with the exception of the emission intensity and the Balmer progression. Other recent research on Pleione includes the publication of an atlas of the shell spectrum between 3167 Å and 4924 Å by Ballereau (1980) and a spectrophotometric study by Sapargalieva (1978).

o And. This very interesting object has a long history of spectrum variations. It has changed from a normal B-type star to a shell star and back again a number of times, and also shows more rapid variations. Various models have been proposed to explain the spectroscopic and photometric behavior of o And, but no general agreement exists. Recent radial velocity and equivalent width measurements by Fracassini, Pasinetti, and Pastori (1977, 1979) suggest a 1.6 day period(supporting an earlier contact-binary system hypothesis) as well as a shell period of about 30 years. The latter has been questioned by Harmanec et al. (1977) and by Gulliver and Bolton (1978), however, whereas the binary hypothesis was also challenged in earlier photometric work and by Gulliver et al. (1980). Other hypotheses which have been proposed (and attacked) to explain the photometric and spectroscopic variations of o And include rotation of a photospheric spot, pulsation, and variable shell absorption. Obviously, more observations of this bright and interesting star would be very desirable.

γ Cas. Discovered by Secchi to show Hβ emission in 1866, this first Be star continues to be a fascinating object. γ Cas was announced to be an X-ray source by Jernigan (1976). Cowley, Rogers, and Hutchings (1976) then looked for radial velocity variations on spectrograms taken over an 18-year period and concluded that γ Cas is probably a single star, although they could not rule out the possible existence of a low-mass companion. Marlborough et al. (1978) suggested a coronal model for the emission from γ Cas, based on the variability of ultraviolet data from Copernicus and Hα scans. They reviewed and rejected as implausible for γ Cas the detached-ring hypothesis and the late-type companion mass-exchange model for explaining the observed V/R variations. Instead, they proposed a modified stellar wind model in which turbulence produced by differential rotation near the equatorial plane leads to the production of a coronal layer above and below the equatorial plane. The V/R variations are explained in terms of a 1 $M_\odot$ neutron star companion with orbital period of about 4 years, which also produces the observed transient X-ray flux.

ϕ Per. This is another controversial object. At IAU Symposium No. 70, one investigator (Hendry, 1976) suggested on the basis of radial velocity measurements that the system is made up of a B1 primary and a B3 secondary, both emission-line stars. But Peters (1976) maintained that the UCLA series of spectrograms showed no evidence of duplicity. More recently, Suzuki (1980) has reinterpreted Hynek's data on the assumption that the circumstellar envelope of the star is a gas ring in a stable periodic orbit of the restricted three-body problem. He deduces the masses of the primary and secondary stars to be 20 $M_\odot$ and 4 $M_\odot$, respectively, with the gas ring revolving around the primary star in the orbital plane of the system. Poeckert (1979, 1981), using new spectrographic material, finds masses of 21 $M_\odot$ and 3.4 $M_\odot$, very similar to Suzuki's values, but suggests that the secondary is peculiar in that He II 4686 emission arises from within its vicinity. He believes that the secondary may be the helium core of a once more massive star, its mass having been transferred to the primary.

48 Lib. This is another classical shell star, which has been studied since the time of Struve. Recent work by Aydin and Faraggiana (1978) suggests that although the radial velocity variations are repeated cyclically, the period is not constant, and therefore the simple binary model must be rejected. They consider the multiple-system hypothesis to be attractive but do not have enough data to elaborate a physically reliable model. Variations in the shell density are considered to be responsible for many of the observed spectrum peculiarities. Garcia-Alegre and Lopez Arroyo (1980) have also studied the shell spectrum of 48 Lib during the period 1962-1967, and find an indication of weaker variations in radial velocity superimposed on the 9.6 year major variation.

Other Stars. In addition to the aforementioned objects, the following Be stars were included among recent spectroscopic investigations in the photographic and visual regions: θ CrB (Poeckert, 1979; Poeckert and Duric, 1980), 59 Cyg (Hubert-Delplace, 1981), 27 CMa (Danks and Houziaux, 1978), 88 Her (Hirata, 1978), ζ Oph (Ebbets, 1980 -- note that the star is erroneously listed as θ Oph), HD 51480 (Welin, 1979), HD 58050 (Ballereau and Hubert, 1981), HD 118246 (Turner et al., 1978), HD 183656 (Aab and Vojkhanskaya, 1977), HD 200775 (Altamore et al., 1979), and HDE 245770 (Giangrande, 1980). Pöllitsch (1979) also reported spectroscopic observations of six bright Be stars.

7. CLUSTERS AND EVOLUTION

The evolutionary status of the classical Be stars is still not clear. There is considerable observational evidence (c.f. Slettebak, 1979) that, on the average, they are located one-half to one magnitude above the main sequence. Is this an evolutionary effect? Earlier attempts to explain Be stars as partially evolved objects, in the secondary contraction phase following hydrogen exhaustion in the core, have been criticized on both theoretical (mass loss may also occur in models of rotating stars in earlier stages of evolution) and statistical (the observed number of Be stars relative to B stars is too large to be consistent with the relatively short-duration secondary contraction stage) grounds. It is also significant that several investigators have shown that Be stars in clusters do not occur only above the main sequence but are also found near the zero-age main sequence.

In a study of Be stars in clusters, Schild and Romanishin (1976) suggest that rotating stars can become Be stars in their early hydrogen-burning evolution away from the main sequence, but are more likely to do so after the onset of gravitational core contraction. Lloyd Evans

(1980) investigated Be stars in two open clusters and also concluded that Be stars are most likely to appear in the core contraction stage of evolution.

Abt and his co-workers have found a number of Be stars in open clusters; his paper on the occurrence of abnormal stars in open clusters (Abt, 1979) summarizes his findings and includes references to his earlier papers. For 13 Be stars in five clusters, Abt finds the mean frequency of Be stars to be about 9 percent (Schild and Romanishin had found about 7 percent), which he considers to be comparable to the frequency for field Be stars. There is a considerable variation from cluster to cluster, however; Abt obtains values between 5 and 16 percent, and Sanduleak (1979) finds at least 34 percent of the early B-type stars in NGC 663 to have shown Be characteristics at one time or another. Sanduleak and Bidelman (1979) also estimate that the open cluster χ Per has about a 25 percent representation of Be stars. It seems clear that the Be phenomenon, whatever it might be, is not an isolated event that occurs to an occasional star.

Abt (1979) also finds that the frequency of Be and shell stars in open clusters shows no strong dependence upon age. Such stars occur among the youngest ($10^{5.7}$ yr.) and oldest ($10^{8.8}$ yr.) clusters in his sample. These investigations suggest that Be stars form early in the cluster histories, with a possible formation spurt at the onset of gravitational core contraction.

Finally, it should be mentioned that rotationally-induced gravity darkening may also play a role in understanding the average position of Be stars above the main sequence. A recent paper by Collins and Sonneborn (1977), based on extensive model calculations, suggests that the position of the Be stars above the main sequence can be interpreted as the result of rotation alone, without invoking evolutionary arguments. Slettebak et al. (1980), in a study of the effects of stellar rotation on spectral classification, provide support for this idea from line strengths: the combination of predicted Balmer line weakening plus the predicted behavior of He I/Si II and He I/Mg II line ratios suggests that rapidly rotating B-type stars viewed equatorially will be assigned luminosity classes which place them somewhat above the main sequence. These rotational effects could also combine with evolutionary effects to explain the position of the Be stars on the H-R diagram -- unfortunately, we cannot distinguish between them at this time.

8. CONCLUDING REMARKS

Even though many exciting results and ideas regarding classical Be stars have come from the opening up of new wavelength regions, it seems clear that spectroscopic observations in the photographic and visual regions are still of the greatest importance. Further study of the Oe stars and the A-type shell stars, which appear to represent extensions of the Be phenomenon, seems important to me, particularly with respect to the problem of shell formation. More observations to define the nature of Be-star variability on various time scales also seem very desirable. We now have much better coverage of changes in the spectra of the brighter Be stars than was available a few decades ago, which makes it possible to attempt modeling some of them. Others have so far defied any reasonable explanation of their spectroscopic behavior, and continued observations would be desirable. More work on Be stars in clusters might throw additional light on their evolutionary status.

Although Be-star spectroscopists have been very active since our last Symposium in 1975, there is obviously still much to be done. It would be fascinating to hear and difficult to guess the content of the papers presented at IAU Symposium No. 523 in the year 2066 (on Be stars, naturally, in honor of the 200th anniversary of the discovery of the first Be star), but we can be certain that most of them would call for more observations.

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DISCUSSION

Coyne: Is there a best M_V to use for Be stars for determining photometric distances?

Slettebak: No, we cannot specify a single value.

Viotti: First I like to stress the importance to concentrate the observational and theoretical effort to a number of representative stars, as you suggested.
Secondly I would like to know how much brighter than MS stars some Be stars really are since dilution effects in extended atmospheres of Be stars may affect the luminosity classification. How much could the luminosity be affected by the assumption of the B.C., being that of non-emission B stars, and of the intrinsic $(B-V)_o$, which could be anomalous.

Slettebak: I do not believe that dilution effects affect the luminosity classification significantly since the sharp absorption lines from the shells are rather easy to distinguish from the usually broad lines from the underlying star.
I regret that I cannot answer your second question, which is a photometric one.

Endal: I was surprised to hear that the subgiants and giants have the same rotational velocities as the main sequence Be stars. If the luminosity classification is correct and rotation is nearly critical, I would expect the stars with larger radius to have slower rotational velocities.

Mermilliod: You did not mention the stars Abt has described as "sn". He believes that this feature may originate in a weak shell. Can you comment on them.

Slettebak: The interpretation of the Abt "sn" stars is somewhat controversial. I believe that the broad Helium lines in the spectra of these stars may have rather sharp cores which are not visible in low resolution spectra, in which case they are not shell stars. But it would be very desirable to obtain high resolution spectrograms to investigate this point.

Stalio: In your list of desiderata I would like to add the necessity to have simultaneous observations from ground and space (UV, X-ray domain).

Marlborough: (Request by Slettebak concerning comments on role of magnetic fields): Magnetic fields deduced from the measurement of circular polarization refer to the line of sight component of the field averaged over the surface of the star. Very large, small scale fields can be missed by this technique. Hence magnetic fields may be important dynamically.

Poeckert: (Question to Sonneborn): 1) Has a "rotating" zero age main sequence been developed?
2) Can one indicate a band in the HR diagram in which rotating ZAMS stars can be found?

Sonneborn: To the best of my knowledge, the effects of rotation on the ZAMS have not been taken into account. Furthermore, a rotational bias is built into the photometric systems, by using rapidly rotating stars as standard stars (for example, α Leo). Work is in progress to determine the rotational speeds of the ZAMS (in a colour-magnitude diagram) from theoretical atmosphere models.

Mermilliod: There is a lack of observations for faint unevolved stars in open clusters which can be used to define the ZAMS. Also information on binarity would be needed too, because axial rotation effects can be confused with binarity effects in the colour-magnitude diagram.

Henrichs: You mentioned that during the 36^h simultaneous observation of γ Cas in the H_α and UV region (Slettebak and Snow, 1978) an X-ray flare was seen when you saw an "event". To my knowledge γ Cas is a highly variable X-ray source and therefore this apparent covariability might well be just a coincidence. Perhaps Dr. Peters, who reported this X-ray observations could comment on that.

Peters: According to Polidan (private communication), prior to the X-ray flare in early 1977, γ Cas (MX0053+60) was in a low state with the Copernicus counting rates varying from 1-4 counts (AV: 2.6 cts). During the pointed observation, the X-ray flux increased to 29 counts! This was indeed a flare event, not just part of the usual "minute to minute" fluctuations in X-rays that γ Cas typically displays.

Harmanec: I reply to a remark by Dr. Thomas. I want to mention that already in 1970 Hardorp and Strittmatter (stellar rotation, ed. by Slettebak) showed a strong tendency of shell spectra to appear mostly for stars with highest v sin i observed.
I feel it is the due time to start advertising the binary model. In the frame work of the binary model, you obtain different luminosity classes of different Be stars quite naturally - as a consequence of a) different extent of the Roche lobe around the gainers, b) different rate of mass transfer.

Sonneborn: It is very important to remember that any theoretical study of the effects of rotation on observational properties of stars is independent upon interior models of rotating stars. Our stellar atmosphere work in Ohio State is based on the Sackmann - Arand interiors, which assume solid body rotation. Different theoretical results might be obtained if one were to use interior models with differential rotation, for example. The theoretical results are of necessity model-dependent.

Sareyan: We have to be very careful when we speak of rotation. Because we are in fact dealing with line broadening, and line broadening can actually be produced by rotation, but also by many other effects, like velocity gradients in the atmosphere, for instance. (Line broadening is being observed, and rotation is only one interpretation.)

Thomas: I question several statements:
1. Be stars are defined only as those having at some time shown Hα emission. Rotation is an inference, not an observation; broad lines are a fact.
2. I do see how you assert "shell stars" have a definite limit on i: especially since shell phase can be transient and non-repetetive in any fixed time-scale. (Compare 59 Cyg and ρ Oph.)
3. You ask how can a shell arise abruptly, while a wind flows continously. We observe that winds change equally as rapidly as do shell phases.
4. You ask how a shell can exist in presence of a wind: a shell is a phenomenon of the wind.

Sareyan: 1) The distance of Be stars from the main sequence is about 3/4 of a magnitude and it is related to "rotation". The so-called "classical β Cephei" stars are typically class IV stars, i.e. situated above the main sequence, like the average Be star. These "classical β Cephei" are "slow rotators", so we can't expect the shift from the main sequence to be due to "rotation", at least for those stars.
2) However, in the very middle of the so-called "instability box" of these 16-18 historical "classical β Cephei", new short period light variables have been discovered, which are now considered as β Cep, and which have very large line broadening, i.e. about 300 km/s.

Slettebak: I would not expect the position of β Cephei stars (or any group of slowly rotating stars) on the H-R diagram to be affected by gravity darkening effects.