Popper: The sample is very small to have conclusions of a statistical nature. I know of no selection effect that would work against finding giants of 1 or 1·5 solar masses.

Popper (additional comment): I neglected to point out that my results on solar type eclipsing binaries do not contradict Eggen's conclusion that the Sun-Sirius mass-luminosity relation is populated only by stars with appreciable ultraviolet excess.

4. ON THE SYSTEM OF β LYRAE

*J. Sahade**

During the war years, Prof. Struve engaged in an intensive programme of spectrographic observations of spectroscopic binaries, principally eclipsing variables. The choice of the subject was partly due to his inclination towards the study of double systems, evident from the very beginning of his work at Yerkes, but it was also due to the fact that, because of the war effort, the Yerkes Observatory was short of astronomers and Struve thought that he could help maintaining the output of Yerkes and McDonald by engaging in a subject which was certain to yield publishable results—at least orbital elements. We all know what the outcome was and where it led to.

Prof. Struve had a strong preference for the interpretation of systems that posed a challenge and as a consequence, peculiar close binaries were always in his observing programmes. Genesis and evolution of double stars and of planetary systems were the problems permanently present in the back of his mind.

As we know, we can distinguish several groups of systems that are peculiar in some ways and, in most cases, pose a problem of interpretation from the evolutionary point of view: the systems where one of the components is a Wolf-Rayet or an Of object, the Algol systems, the W Ursae Majoris systems, the cataclysmic variables, perhaps the metallic-line stars, perhaps also the *V/R* variables, and the group with underluminous, massive components, to the existence of which I have called attention recently (**1**).

In this paper I shall refer to β Lyrae which belongs to the latter group. β Lyr is an object, if not *the* object which merited more thought and effort from Prof. Struve than any other of the several hundred stars he investigated during his lifetime. As it is well known, β Lyr has a period of about 13 days, with no constant light at any phase of the orbital cycle. Its spectrum displays several sets of absorption as well as of emission features that arise from different sources; they have been described elsewhere (**2**). One of the sets of absorption lines arises from the primary component of the system, a B8 object of luminosity class II or III. Another set of absorption lines shows the effect of diluted radiation and originates in a gaseous envelope that surrounds the whole system, while broad absorption lines that are observed immediately before and immediately after mid-eclipse had been interpreted by Struve (**3**) as being the result of absorption effects of gaseous streams going from the secondary star towards the primary and from the latter component towards the former, respectively, seen projected upon the disk of the

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B8 object. No absorption features that could be ascribed to the companion to the B8 star have been found.

Although already in 1941 Struve (3) pointed out that one of the aspects of the problem of β Lyr that deserves study was that of the varitations of structure and intensity in the emission lines, the investigation so far made of β Lyr have been mostly confined to the absorption lines. The reason of this lies in the fact that the complex emission pattern cannot be easily studied in the photographic region. Furthermore, the complexity of the emission features themselves is made even more so by the presence of absorptions that cut across them. The most important results that came out from the earlier study of the emission lines are those of Belopolsky (4) and of Curtiss (5) who found that the emission at Hβ yielded a velocity curve that was smaller in amplitude and 180° out of phase relative to the velocity curve of the B8 component. These results were not confirmed by Baxandall (6) who investigated the star several years later. Baxandall's spectrograms clearly showed that the broad H emission shifted opposite in phase with respect to the lines of the B8 component, but, partly because at some phases there were coincidence of one emission edge with the position of the absorption lines from the B8 star and partly because Baxandall may have measured the emissions at several members of the Balmer series and perhaps also because the emission might have been more complex at the time of his spectra, Baxandall's measures failed to yield a velocity curve. They rather yielded one set of positive velocities in the range of 120–225 km/sec which roughly suggested orbital motion and another set of negative velocities in the range of 20–90 km/sec which suggested a straight line. Baxandall was then led to think that the set of absorption lines that shows the effect of diluted radiation, the practically stationary 'B5 spectrum' as it was called at that time, was the spectrum of the secondary component of the system of β Lyr.

A few years ago, when at Berkeley we made an investigation of the spectrum of β Lyr, the emission was described (2, 7) as 'being formed by a broad feature upon which a stronger, narrower emission is superimposed'. 'The narrower feature' which was designated as an emission peak, 'stands out very clearly during the eclipse'. Although it was stated (2) that probably the 'emission "peaks" are parts of P Cygni-type profiles, the violet absorption edges being undetected because of the relatively faint continuous spectrum from the secondary component', the description quoted above was very unfortunate and evidently misleading as it induced Huang (8) to interpret the emission 'peaks' as produced by atoms falling towards the secondary component of the system and to suggest that β Lyr may be a transition object to the Algol-type configuration.

In order to make progress in the understanding of β Lyr, 83 spectrograms taken in the red region (Hα and He I λ6678 were studied; sometimes also He I λ5876) with the coudé spectrograph of 100-inch Mount Wilson telescope (20 Å/mm dispersion) and 9 spectrograms taken with Cassegrain X-spectrograph attached to the 60-inch Mount Wilson reflector (40 Å/mm dispersion) were studied by Carlos Hernández and myself (9). The distribution of the material, taken in 1957 and 1958 mostly by the late Prof. Struve (a few by myself), with a different purpose in mind, was concentrated at around primary minimum; nevertheless, the spectrograms provide useful information, which can be described as follows:

1. The examination of Hα, and He I at λ5876 and λ6678 suggests that the emission is composite; a strong emission is superimposed upon a broad, fainter bright feature (half-width of about 700 km/sec on the average).

2. The emission is cut by absorptions which give the stronger emission the appearance of a 'peak', as it was described earlier. If one measures this 'peak' one obtains velocities with γ displaced about 100 km/sec towards the red in agreement with the results obtained at Berkeley (2) when measured the 'peak' in the photographic region.

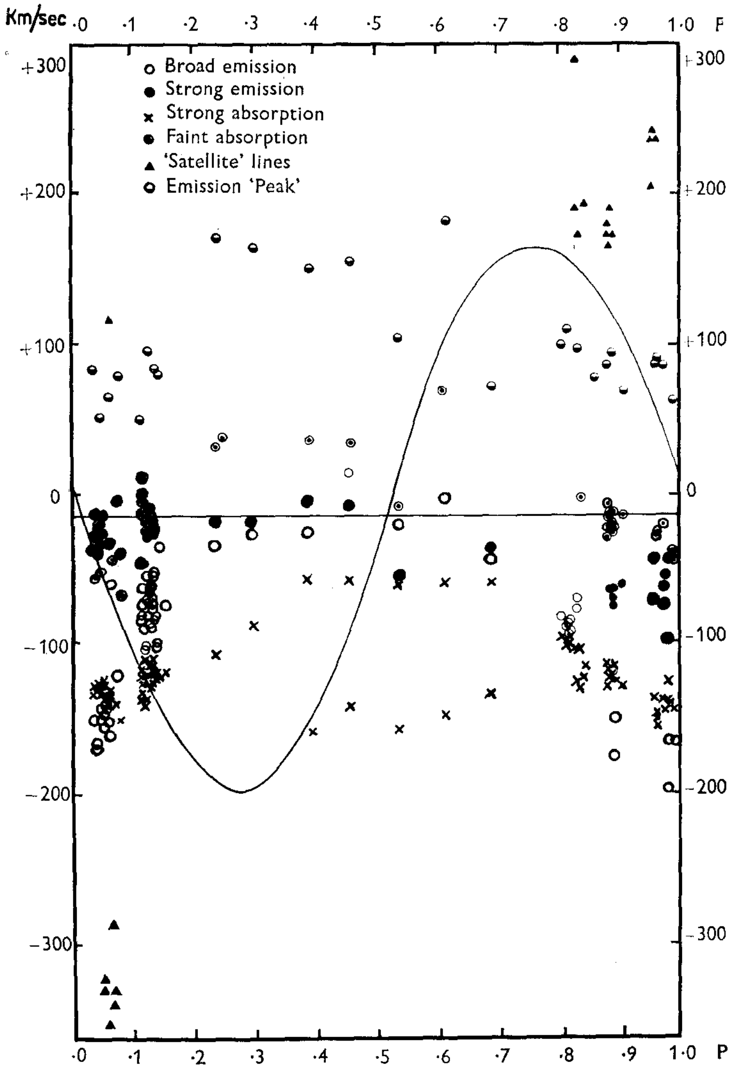

Fig. 1. Velocity curve from Si II as derived by Sahade, Huang, Struve and Zebergs (2) and radial velocities from the complex structure of He I λ6678.

3. At the three wavelengths mentioned in (1) the lines of the B8 star are not observed. The absorptions that are seen are:

(*a*) absorptions that are produced by the expanding surrounded envelope (crosses in Fig. 1); in our case, however, we find only two distinct sets of constant velocity rather than the several sets we found in the Berkeley measurements in the photographic region.

The velocity values that seem to result from the material on which this paper is based are of

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the order of -150 km/sec and -50 km/sec and it is interesting to note that the absorption yielding the smaller value line is distinctly there from about phase 0·2 P to about phase 0·8 P.

(*b*) The so-called 'satellite' lines, are present on our plates in the phase intervals from about 0·85 P to about 0·95 P and from about 0·02 P to about 0·075 P (triangles in Fig. 1).

(*c*) A faint absorption which is immediately to the violet of the emission 'peak' as mentioned under (4).

4. If we measure the emission 'peaks' as in the work at Berkeley we obtain the same distribution of velocities as then (half-filled circles in Fig. 1). However, the actual strong feature extends towards the violet and it is cut by the absorptions, one of which, the close to the 'peak' (rings in Fig. 1) yields a similar velocity distribution (although there is some distorsion due to blending). The fact that the 'peak' is not a physically-significant feature is indicated by the velocity distribution of the violet edge of the strong emission which suggests practically a straight line at about -220 km/sec.

5. The velocities from the strong emission (dots in Fig. 1) suggest a trend opposite in phase to that of the velocity curve of the B8 component. Unfortunately, the material available is rather meagre.

6. The broad emission yields velocities (open circles in Fig. 1) that are very negative during eclipse (as negative as about -200 km/sec) but out of eclipse they show some scatter around the systemic velocity. During eclipse the broad emission appears to be broader than outside of eclipse.

We interpret the broad emission as arising from material that is located mostly between the two stars and during eclipse we must be observing the mass of gas that is leaving the system through the Lagrangian point that is in front of the secondary in agreement with the accepted interpretation (**3**, **10**).

The stronger emission must arise from material around the secondary component that partakes its motion around the centre of gravity of the system. The difficulty in measuring emission edges makes it unwise to try to conclude anything in regard to K_2 except that undoubtedly $K_2 \ll K_1$.

The faint absorption immediately to the violet of the 'emission peaks' gives a velocity distribution that must be affected by the fact that in the second half of the cycle the violet edge probably extends more to the violet than what the presence of the stronger absorptions permits to realize. The faint absorptions would then suggest a velocity curve approximately opposite in phase to that of the B8 star. The absorption material must be in front of the material that gives rise to the strong emission; it may very well be that we are observing absorption effects of the outer parts of the material that surrounds the companion to the B8 star; the difference in width of the two features would then mean that there is conservation of angular momentum in the gaseous material.

If further investigation should confirm the above considerations then we would be actually observing absorption lines connected with the secondary component of the system.

In Fig. 2 we have plotted the radial velocities derived from the measurement of Si II $\lambda\lambda$6347 and 6371 where during eclipse we see two and sometimes even three components: one component corresponds to the B8 star, another component gives velocities that makes it coincide with the 'satellite' lines. We have found no interpretation for the third component.

Let us now refer to the question of the masses. In dealing with this problem we can distinguish three very marked epochs. The first epoch goes as far back as 1893 when Belopolsky found that the broad lines of the emission at Hβ gave a velocity curve opposite in phase and

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smaller in amplitude than that from the B8 star. Belopolsky concluded that the implication of his work was that the companion to the B8 star displayed emission lines and that the latter was the less massive component. The masses that were suggested by the amplitudes of the two velocity curves were 9·5⊙ for the B8 star and 21⊙ for the companion. Belopolsky's results were confirmed by Curtiss who derived mass values of 6·8⊙ and 16·6⊙, respectively.

Several years later Baxandall made a new spectrographic investigation of β Lyr to which we have already referred to. Although, as we mentioned, Baxandall thought that the secondary

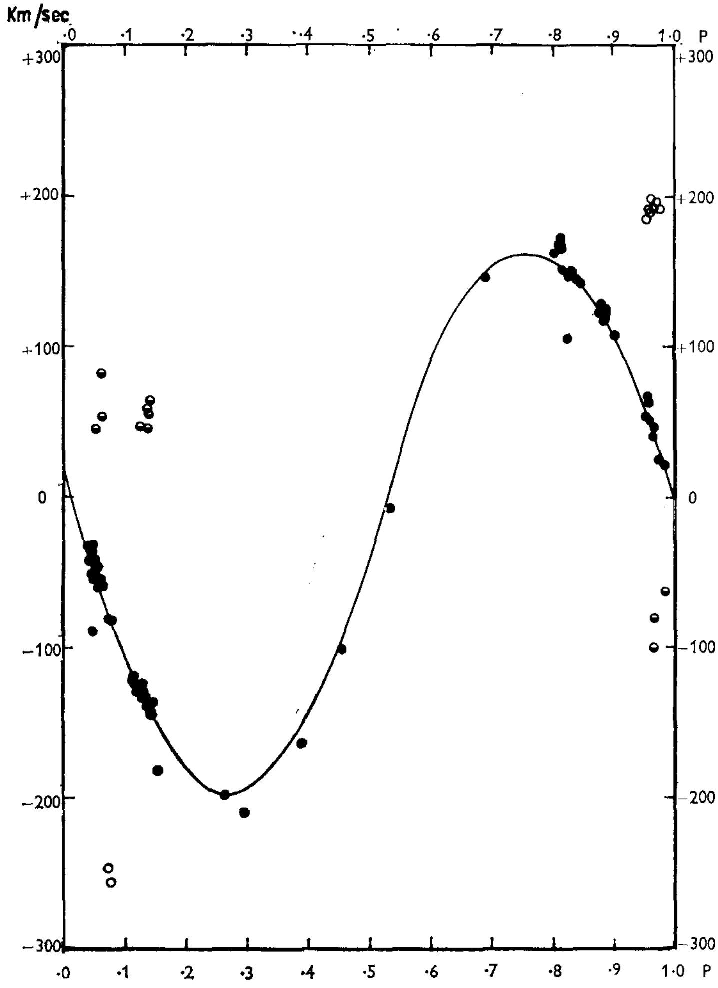

Fig. 2. Radial velocities from Si II λλ6347 and 6371.

component of β Lyr was represented by the so-called 'B5' spectrum, his conclusion was that the 'B5 star' is the fainter and more massive component.

It is interesting, then, to stress the fact that before 1940 the ideas regarding β Lyr were that the B8 star was the less massive component of the system.

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A second epoch in the interpretation of the mass situation in β Lyr goes as far back as 1940 when a very strong co-operative effort was made at the Yerkes Observatory to understand a system as peculiar as β Lyr. The belief at the time that the mass-luminosity relation always hold led to masses of the order of $80\odot$ for the B8 component and $50\odot$ for the 'invisible' companion, that is to a model where the B8 star was the more massive component of the system.

A third epoch is the present one where we find that the available evidence leaves little doubt that the B8 star is the less massive component of the system. This third epoch in the understanding of β Lyr started at around 1955. In a paper that Struve (**11**) presented at the IAU Symposium on non-stable stars, he mentions the problem posed by the luminosity of the B8 star for which the spectroscopic evidence was in favour of one that would lead to a mass smaller than that of the companion. But the time was not ripe yet to accept this.

A year later Gaposchkin (**12**) revived the question of the luminosity of the B8 star as suggested by the spectrum and by the values of the masses derived by Belopolsky. The mass-luminosity relation was still to hold and as a consequence it was necessary to assume that the companion to the B8 star was 'camouflaged' by a thick atmosphere.

A new way of considering the problem came from the study of the series of plates taken in 1955 by Struve and myself at the Mount Wilson Observatory. Because the emission once again seemed to yield a velocity curve opposite in phase and of smaller amplitude, although of different γ, than that of the B8 star, it was then accepted that the mass of the B8 component was smaller than that of the other component, that the former was evolving away from the main sequence and that the latter, being more massive, was evolving towards the left after having reached the end of its evolutionary track to the right (**13**, **2**).

Huang (**8**) has advanced two other possibilities of interpretation of the present stage of β Lyr, namely, (*a*) that the contraction of the companion to the B8 star has been retarded because of the angular momentum of the pre-stellar material being extremely large; (*b*) that originally the mass of the primary was larger than that of the secondary and that β Lyr is in the way of becoming an Algol system.

The question of the evolutionary stage of β Lyr may still be subject to argument, but what is now generally accepted is the fact that the B8 star is the less massive component of the system. This conclusion is based on the fact that the luminosity of the B8 star is not very large, $-2{\cdot}7$ according to Boyarchuk (**14**), $-3{\cdot}9$ according to Abt, Jeffers, Gibson and Sandage (**15**) and that no appreciable mass loss has taken place since the star began its evolution away from the main sequence.

The considerations made in regard to the emission features and the characteristics of the secondary component of β Lyr (in regard to mass, size, etc.) does not lend support to the hypothesis that we are dealing with a transition object to the Algol-type systems. Actually, β Lyr, as we have pointed out elsewhere (**1**), is a member of a group of objects that are characterized by the fact that the secondaries are underluminous, massive stars, usually smaller than the primaries and usually surrounded by an extended gaseous envelope. The group includes HD 47129, AO Cassiopeise, V453 Scorpii, V448 Cygni and probably HD 698, ϵ Aurigae and W Crucis.

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DISCUSSION

Morton: Calculations made at Princeton a few years ago can explain one major feature of the β Lyrae system, namely why it is the less massive star which fills its Roche limit. Initially, the internal evolution of the more massive component causes it to expand to fill its lobe of the Roche limit. Then two factors determine whether the star loses mass across the inner Lagrangian point to the other component. These are, the change in the evolving star's equilibrium radius and the decrease of the radius of the Roche lobe caused by the change of mass ratio. It has been shown that the latter radius decreases faster until a large fraction of the evolving star is transferred, leaving it now the less massive component and filling its lobe of the Roche limit. Perhaps enough mass is removed to expose the helium rich layers, thus explaining an observation by Struve that the B8 component of β Lyr has an over-abundance of helium.

Hack: In regard to Dr Morton's remark let me point out that from quantitative analysis of β Lyr the ratio H/He comes out of the order of 1/10 in number of atoms, while for υ Sagittarii, which probably represents a more extreme case of loss of matter, the ratio H/He is about 1/50.

Popper: If we accept a mass of around 18$\odot$ for the secondary component of β Lyr, the absolute magnitude of which is -1 or so, I think, does this mass-luminosity combination not impose a very serious difficulty to the stellar models?

Morton: The simple picture of mass transfer is most relevant to the Algol systems. It is intended to describe only one of many complicated processes which must be occuring in β Lyr.

Sahade: If I remember correctly, Dr Morton's computations were made on the assumption that mass lost by the present secondary is to be gained by the star that is presently the primary component. But this, in the first place, will certainly partly depend on the velocities of the particles flowing away. Furthermore, we should not forget the fact that in many of these systems we find evidence for the existence of an expanding envelope, thus, suggesting that matter is escaping from the system. On the other hand, at least in these systems, no feature has been found that could be interpreted as evidence for matter being gained by one of the components, that is, for matter falling on one of the stars.

Reuning: If presently accepted orbital and system parameters for β Lyr are used, representation by either the classical Roche surfaces or by critical distorted-polytrope surfaces (after Chandrasekhar, *Mon. Not. R. astr. Soc.* **93**, 462, 1933) requires that the B8 component be the less massive, if this is to be the component subject to mass loss and stream emission. For any accepted values of the mass ratio, the radii, and the separation, the more massive component in either case lies very safely inside the critical surface by either method. Using Huang's model, the distorted-polytrope method shows a small instability zone or cap in the B8 star, facing the more massive star, where the force vector is directed outward.

Gratton: I would like to recall the fact that due to the binary character and the fast rotation of β Lyr and similar stars, we must expect internal circulation so strong that it is very doubtful whether the usual theory of evolution may be applied at all.

Morton: We now observe the less massive component, which fills its Roche limit, in a state of equilibrium in which any further mass loss would decrease the radius of the star faster than the radius of the Roche lobe. It is unlikely that we should catch many systems during the transfer process which must occur on a Kelvin time-scale or faster.

Sahade: I would like to point out that there is a marked difference between the Algol systems and the β Lyr type of objects, namely, that, although in both cases the secondaries do not obey the mass-luminosity relation, in the former they are overluminous for their masses while in the latter type of systems they are underluminous for their masses. Moreover, the mass function in the Algol systems is very small and suggest, by making reasonable assumptions, that the masses of the secondaries are also small and, in many cases, much smaller than the mass of the Sun. On the other hand, in the β Lyr group the masses of the secondaries are large, several times larger than that of the Sun.

McLaughlin: The slide of the λ6300 region showed apparent sharp doubling of the Si II absorption lines at certain phases. Dr Sahade did not refer to this, and I did not have a long enough view of the slide to attempt an interpretation. Could we have a comment on this?

Sahade: One of the components gives velocities that agree with the lines of the shell which surrounds the whole system, while the other arises from the primary (B8) star.

5. PROBLEMS OF THE ALGOL SYSTEMS

M. G. Fracastoro

DEFINITION OF THE GROUP

We have on record several attempts to divide the eclipsing binaries into groups, starting from different points of view (**1, 2, 3, 4, 5, 6**). Probably because of historic reasons, Algol has been considered for many decades as the prototype of systems constituted by two very different stars, showing little or no mutual influence between them. However, as the accuracy of its light curve was increasing, and the spectroscopic inspection was progressing, Algol showed a secondary minimum (and this was the first evidence that the companion was not photometrically negligible) and then a reflection effect, as a further evidence of a mutual influence between the two components. Algol also showed many spectroscopic peculiarities, mainly due to exchanges of material between the two components. Therefore, we may include in the Algol group all typical semi-detached systems, with a main sequence B-type star as primary, and a subgiant companion having more or less the same mass and spectral type of our Sun, but being over-luminous and oversized, and therefore well above the main sequence.

Many systems appear to belong to this group, even when period, spectral type, relative sizes and temperature of the components, and even the amplitudes of the minima are required to be similar to those showed by Algol itself. It appears, therefore, that the association which we observe in Algol is very frequent among the binary stars. The association of a main sequence