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 $\lambda 6300$ 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

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early-type star with a true giant or a supergiant, instead, brings us to systems which appear physically quite different from the Algol-type systems, and particularly the period increases up to very long values, as those shown by the ζ Aur group.

Struve and his collaborators have pointed out that one of the most interesting features of the eclipsing binaries (and particularly of the semi-detached systems) is their ability to show the spectroscopic evidence of these mutual influences. Struve's contribution to this problem can hardly be overestimated. He has suggested the basic ideas for a very fruitful line of research and has made innumerable contributions for the interpretation of many specific systems.

THE PERIOD AND ITS VARIATIONS

The period P is one of the most important features characterizing a binary system. In general, the longer is P, the bigger are the two components of an eclipsing pair. A paper by Prikhodko (**7**) shows that, among 96 eclipsing binaries, 70 show variations of P and the magnitude of this variation increases very rapidly with P. However, when we take only the semi-detached systems into account, a definite relationship between log ΔP and log P is no longer evident.

Systematic observations of times of minima have made it almost certain that sudden changes of P are really occurring for several systems. According to the suggestion first made by Wood, these sudden changes of P always speak in favour of ejection of material, and he has shown (**8**) that negative, as well as positive ΔP may occur, according to the point from which the ejection takes place.

Of course, cyclic variations of P may be also observed and they can arise from apsidal rotation or from the presence of a third component. A more complicated trend of the $O - C$ curve of the minima has sometimes been interpreted as due to the overlapping of several cyclic curves, necessarily assuming the presence of several members of a multiple system. This conclusion, however, needs always to be checked and the invisibility of these members should agree with their hypothetical absolute magnitude and the annual parallax of the system.

The prototype of our group, Algol, can show any kind of ΔP: one cyclic variation has $P' =$ 1·873 years and amounts to $\pm$ 5 minutes. It is due to the light-time equation resulting from the orbital revolution of the eclipsing pair around the centre of mass with respect to a third body. Other cyclic changes of P, with longer periods, are suspected. Finally, we have the so-called 'great inequality', which amounts to several hours and might be interpreted as a cyclic variation of P with a $P'' = 188$ years approximately. On that subject, however, we may recall an early suggestion by Sterne that the great inequality could be explained on the assumption that in 1840 the primary period has suffered a sudden change of $-4{\cdot}9$ seconds.

THE LIGHT CURVE. PHOTOMETRIC PROBLEMS

Apart from variations due to eclipse, we assume that an eclipsing binary should have a constant luminosity. Therefore, we 'rectify' the light curve, by introducing as many Fourier coefficients as requested for constant light outside eclipse. For a given position angle θ, the fractional luminosity $L(\theta)$ will be:

$$L(\theta) = L_0 + A_1 \sin \theta + A_2 \sin 2\theta + \ldots + B_1 \cos \theta + B_2 \cos 2\theta + \ldots$$

This is a purely mathematical procedure, and the various coefficients A_i and B_i do not necessarily correspond to a precise physical phenomenon or vice versa (**9**), apart from B_1 and B_2 which traditionally represent the reflection and the ellipticity effects.

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Up to the present time, the problem is to ascertain: (*a*) how many light curves actually show these anomalies outside or during eclipse and therefore how far the reality of these coefficients goes, (*b*) whether – comparing light curves of the same eclipsing binary, taken with different pass bands and located in different spectral regions—these coefficients remain substantially unchanged, (*c*) whether these coefficients retain their values when reobserving the same eclipsing binary after one or several years, (*d*) whether we may find eventually any cyclic variation in the light curve, (*e*) whether, comparing light curves of similar systems, we can find any similarity among these coefficients.

The answer to item (*a*) is that, as the accuracy of the photometric measures increases, the number of systems showing such anomalies increases steadily. These anomalies usually take the form of humps in the parts of the light curve outside the eclipse. On the other hand, the dependence on λ of these humps, according to item (*b*), may help to explain their physical meaning. Anomalous behaviour of the star, in or outside eclipse, if it is due to alterations with phase in the intensity of some spectral lines, will be emphasized by use of narrow band interference filters, centred at the wavelength of the variable line. Pioneer work on this subject has been made by Hiltner (**10**) who obtained a light curve of the Wolf-Rayet eclipsing binary CQ Cephei at $\lambda 4686$ (He II). The same star has been observed by Bappu and Sinvhal (**11**) at $\lambda 5411$ and $\lambda 4861$ (He II). Both authors find maxima of the emission features at primary and secondary minima.

As far as item (*c*) is concerned, we have 'non-repeating' systems not only among contact binaries, but also among semi-detached systems. A variability of the light curve, inside or outside the eclipse, should be tentatively correlated with the variation of the period, if any. Both phenomena are a rather common feature, where contact binaries are concerned. For semi-detached systems, it may be interesting to see how far the mutual perturbation persists, when we take into account more and more separated systems. As a matter of fact, the secondary minimum of Algol itself appears to be changing its depth and shape from time to time. A more evident example is that of SV Cam (**12**). The whole part of the light curve of RS CVn which is outside eclipse varied considerably from 1963 to 1964 (**13**); this star is one of the few examples of the so-called 'negative' reflection, namely the light curve shows a Fourier coefficient $B_1 > 0$. This fact is due, of course, to something quite different from the usual reflection.

As far as item (*e*) is concerned, we have a strong suggestion that the phases which are more likely to show humps are those just after and/or before the main eclipse. U Cep shows a bump, about $0^m.1$ high, around $\varphi = 0^p.11$, and the light curve is quite asymmetrical with respect to $\varphi = 0^p.5$. We have obtained a red curve for Algol, taken with an interference filter centred around Hα. The pass-band of this filter was perhaps too large (about 70Å) for allowing any real correlation of the light curve with chromospheric phenomena. In any case, we have a strong feeling that we see a bump just after the primary minimum, at a phase which is not very different from the corresponding phase of U Cep (**14**). A recent and striking example of a hump just after the primary minimum is given by BM Cas (**15**).

SPECTROSCOPIC PROBLEMS

A typical spectroscopic binary shows periodic variations in the wavelengths of its spectral lines, and we attribute these fluctuations to the orbital motion of the components, assuming that the measured wavelength of the line corresponds to the radial velocity of the centre of the disk. This is true when the star rotates rigidly around its polar axis.

As everyone knows, this picture is far from correct, when close binaries are concerned. In many cases, the observed radial velocities, plotted against phases, give spurious orbital elements. This is especially true for the values of the eccentricity and the apsidal angle, and one may wonder how much the observed radial velocities must depart from those expected for orbital revolution, before we reject these data and conclude that the observed lines do not belong to the component, in the traditional sense: β Aur and β Lyr are extreme cases of correspondingly fitting and non-fitting radial velocities, in the sense that the RV's of β Aur are exactly fitting the orbital motions of both components; those of the so-called B5-component of β Lyr, instead would lead to a completely wrong picture of this system, if they were assigned to 'photospheric' lines. Intermediate examples are HD 47129 and AO Cas.

Faced with striking examples of non-fitting elements, astronomers have been compelled to admit that the lines originate in layers, rings, streamers or envelopes; these features being situated at respectively greater distances from the 'regular' photospheres of the components. From these layers, or similar features, we can sometimes observe emission lines in the spectrum. Their intensity is possibly correlated to the phase, and the Doppler shift can tell us something about the movements of the material. A typical example of this kind of binary is SX Cas ($P = 36^{d}.6$), but emission lines are also shown by RW Tau ($P = 2^{d}.8$), a typical semi-detached system with absolute dimensions very similar to those of Algol itself, and by many others, having more or less the same size, or which are even smaller (for example YY Gem, $P = 0^{d}.81$).

Struve (**16**) estimates that one out of three systems having deep eclipses shows luminous streams of hydrogen or other gases, and points out that probably the lack of observation of emission lines or spectroscopic peculiarities for systems having shallower eclipses is due more to technical reasons than to actual absence of these phenomena.

Let us now say a few words about the spectroscopic story of Algol. More than 50 years ago, several faint sharp metallic lines were discovered in its spectrum. They are particularly numerous and easy to observe during primary minimum. They fit the excitation which can be expected in an F type star. For decades these lines had been attributed to Algol 2, until, in 1923, Barney measured the radial velocities of these lines from many spectra and concluded that they follow the phase of the orbital movement of Algol 1, though with a much lower amplitude. According to Barney, these extra lines do not show any correlation with the 1·873 years period. This tempting picture remained more or less unchanged for 25 years and even Kopal (**17**) interpreted these metallic lines as produced in the outer space between the eclipsing pair. Pearce was the first one to attribute these lines to the third component and, more recently, Meltzer (**18**) from high dispersion spectra obtained with the 100-inch reflector of Mount Wilson, finds that the observed radial velocities of some lines, on spectra taken during the primary minimum, agree with the orbital velocity of Algol 3, and not with that of Algol 2. Furthermore, they do not show any significant spread, so they cannot be attributed, according to Meltzer, to streamers flowing out of the secondary component. Therefore, the question of these lines is considered now to be completely clarified. Huang (**19**) has measured the intensities of some helium lines and their variations during the primary eclipse. He finds that Algol 3 should be only 1·82 magnitudes fainter than Algol 1 and should therefore be more luminous than Algol 2. Incidentally, attempts have been made to ascertain colourimetrically the contribution of Algol 3 to the whole light of the system, especially in the red and infra-red regions of the composite spectrum (**20, 21**). In both cases the determination is difficult because of the relatively small difference between the colours of Algol 2 and Algol 3. From our own red curve, no solution can be obtained unless we assume a contribution L_3 from the third body. The best fit is obtained under the assumption that $L_3 = 0{\cdot}115$.

Many studies have been performed in order to interpret other spectroscopic features which are observed in Algol, mainly at/or near the primary minimum. Struve and Sahade (**22**) have taken spectra of Algol with the 100-inch reflector of Mount Wilson, with a dispersion of 4·5 Å/mm. They studied chiefly the profiles and the radial velocities of hydrogen lines and concluded that the observational facts can be explained by a flow of gas from Algol 2 to Algol 1.

Evidence of concentration of matter at the Lagrangian points is also found in Algol, and Hα,

$H\beta$ and $H\gamma$ appear with emission features at elongations, with a red shift at phase $0^p.25$ and a violet shift at phase $0^p.75$. The emission lines, at the same phases, are doubled in UX Mon, showing the existence of prominences having motions preferentially directed along the line of sight (normally with respect to the orbital axis).

The differential radial velocities of hydrogen lines, when compared with some lines (Si II) which are assumed to be typical low-level lines, have been investigated by Struve and Ebbighausen (**23**). Their conclusion is in favour of an equatorial ring of hydrogen revolving around the main component with a velocity lower than the rotational velocity of the photosphere.

A very interesting feature is the difference in the rotational speeds which has been found for different elements; for instance, in Algol 1, hydrogen rotates more slowly than helium. The same is true for RZ Scuti. A good amount of theoretical research about the rotation of the primary component of close binaries has been made by Walter, in Germany. It might be useful to compare the case of the components of eclipsing binaries with that of a typical single star like our Sun; from its poles to the equator, we find a general acceleration, which is greater for low-level lines than for neutral calcium, or $H\alpha$, or ionized calcium; the last showing the smallest acceleration. Consequently, the V_{rot} is the highest for Ca II and becomes lower and lower for $H\alpha$, Ca I (λ4227) and so on. Thus the Sun has a tendency to wind up around itself, and we may expect similar behaviour for the primary components of semi-detached systems, which are dynamically in a more independent situation in comparison with their mates. The streams running around the primary star have a V_{rot} which is in the same general direction as the photospheric V_{rot}, but has a larger value. Struve has found a tendency for the particles which constitute these streams to satisfy Kepler's third law.

We may add, incidentally, that the radial velocities of the chromospheric lines for ζ Aur and those systems which belong to its family, speak in favour of large-scale motions of gaseous streams in the chromosphere of the larger component. These motions are superposed and may mask the rotational motion. For ζ Aur, the violet shift is, at egress, larger than the red shift; while, at ingress, the reverse is true. For 31 Cyg and 32 Cyg, the violet shift is larger at both egress and ingress, but these systems have grazing eclipses. The motions, which produce these Doppler shifts, vary from night to night, because there is a significant degree of turbulence in the extended atmospheres of these stars. However, the presence of asymmetrical envelopes seems to be a general feature in large systems like ζ Aur (where the chromospheric phase lasts longer before totality than after totality) as well as in dwarf systems like the contact binaries. The decreasing of the periods can be explained through a more pronounced activity of the advancing hemisphere of the subgiant member of the semi-detached system.

EVOLUTION OF ECLIPSING BINARIES

The evolutionary trend of a close binary system depends on various parameters, namely $\mathfrak{M}_1$ and $\alpha = \mathfrak{M}_1/\mathfrak{M}_2$, as well as $(R_1 + R_2)/a$. As far as semi-detached systems are concerned, the evolutionary trend, according to Struve (**24**) and to Crawford (**25**) is the following: the component which initially was the more massive one is presently the secondary component, because it has suffered loss of material at the benefit of its mate. That this material is mainly hydrogen is fully justified, since it is lighter and it can be magnetically bound by only 1 unit of charge. This process produces an alteration in the mean molecular weight, which results in an abnormal heating and dilatation of the star. We do not think it necessary that the ejected material be permanently captured by the primary star, which might dissipate it in the 'Milne' or in the 'intermediate' mode (**26**) and eventually form an envelope around the whole system, or a ring around the main star.

Struve and Hack consider the evolutionary path from detached to semi-detached systems as due to exchange of mass between the components, and to loss of material suffered by the system. The average period for 29 detached systems is $2^d.8$ and for 30 semi-detached systems is $2^d.7$. Huang and Struve think that the spectroscopic observations do not give evidence of sufficiently large mass loss, to account for a positive ΔP as large as $9^s.3$ per year, as observed for β Lyr. Struve suggests that the loss of mass may take place in the form of particles which are spectroscopically unobservable, such as cosmic rays. This possibility has been examined by Huang who considers it possible that both components are embedded in a common 'corona', and calculates that the secondary component of α Vir may receive $5 \cdot 10^9$ protons cm^{-3} s^{-1}, a value which is not far from that observed for our Sun.

Struve and Hack consider the late-type contact binaries (W UMa systems) as non-evolved stars. This conclusion is not shared by Sahade (**27**) who considers these systems as old objects which have evolved through an appreciable loss of mass, from early-type systems having similar components, both on the main sequence.

Finally, Huang (**28**) has suggested that all ex-novae and dwarf novae may be binaries. Kraft (**29**) has made a systematic investigation on 19 of such novae, finding that eight of them are binaries, with orbital periods ranging from 3·5 to 9 hours. The red member supplies material for the ring which in every case surrounds the blue member. Therefore, Kraft suggests that the U Gem stars may represent an evolutionary stage of the W UMa group. But this will be the subject of his own contribution.

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DISCUSSION

Herczeg: I should like to make some short remarks supplementing Dr Fracastoro's lecture. The binary I deal with is β Persei, a typical Algol system indeed, and the results I am going to summarize were obtained mostly at the Hamburg Observatory by Hög and myself. We tried to tackle the question of the number of the components in this system. A third component is well known to exist, its orbital period was recently determined by Ebbighausen as 1·862 years, instead of 1·873 years. Consequently, we rediscussed the important astrometric observations made by van de Kamp and his collaborators. The new elements, however, do not give a significantly different picture. A further step was to analyse these measurements in terms of the 32-year period which also seems to have been well established. A combined solution for both orbits (1·862 and 32 years) was made, but it turned out to be impossible to obtain any reliable elements for the latter. That periodicity thus represents very probably an apsidal motion, as already proposed by various observers. Photoelectric measurements at the field station of the Bonn Observatory seem to lend additional support for this proposal.

We were able to derive the luminosity of Algol C, too, by comparing the astrometric measurements made in maximum light with those taken during the eclipse. The brightness difference between AB and C amounts to $2{\cdot}1 + 0{\cdot}6/-0{\cdot}3$ magnitudes.

An effort is being made to check the reality of a further component causing the light-time effect known as the 'great inequality' (period about 180 years). A preliminary inspection of the meridian positions given to us by the editors of the FK4 fails to show the corresponding orbital motion.

Chou: From the analysis of about 1600 available times of minimum by means of autocorrelation method, five terms of variation in period are found. These are 1·8, 14, 19, 32 and 187-year terms. The 14-year term is the less probable one. The 1·8-year term is now well understood, but we are not so sure about the 187-year term which has been suspected as due to an extra component star, namely the fourth body. The 32-year term which has been regarded as due to the rotation of the line of the apsides of the two-body orbit should be reinvestigated because the calculation of the polytropic index assuming that the 32-year term is due to the motion of the line of the apsides comes out with 3·6 which is rather high as compared with the value for the stellar model which Eddington had suggested.

The 19-year term gives a better value for the polytropic index which is closer to that of the Eddington's model. Therefore, I believe that the 19-year term is more probable than 32-year term as due to the motion of the line of the apsides of the two-body orbit.

Hack: As a matter of fact, from our spectrograms of ζ Aurigae taken at Merate during the last eclipse, it appears that the chromospheric K line is visible about 38 days before totality and disappears 25 days after totality, showing the existence of the usual asymmetry.