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LY AURIGAE, NY CEPHEI, AND THE MASS-LUMINOSITY ANOMALY WITHIN O TYPE BINARIES

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ABSTRACT

The luminosities of the components in a number of double-lined O type binaries appear more nearly equal than predicted from their mass ratios. Critical examination shows that this anomaly is best established in the contact binaries LY Aur, V382 Cyg, and 14 Cep, and may be a general property of contact binaries of type O. The published mass ratios of LY Aur and NY Cep require considerable revision, making the two components in each system more nearly equal in mass than given heretofore.

Subject headings: mass-luminosity relation — stars: early type — stars: eclipsing binaries — stars: individual

I. INTRODUCTION

The frequency of double-lined spectroscopic binaries with mass ratio, $Q = m_1/m_2$, greater than 1.3, say, is very low (e.g., Lucy and Ricco 1979). The true frequency of larger mass ratios in all binaries is, of course, considerably greater (e.g., Trimble 1978), the difference being a consequence of selection effects: Because of the strong dependence of luminosity upon mass, the lines of the less massive component become more and more difficult to detect and measure as the mass ratio increases. The most numerous double-lined systems with larger mass ratios are found among the W UMa binaries. The existence of this group of systems, violating the relation between mass ratio and luminosity ratio based on theory and observation of wider binaries, has led to a large body of theoretical investigations (e.g., Shu 1980). I have pointed to the presence of several double-lined O type binaries of luminosity classes III–V, without apparent spectroscopic complications, also not conforming to the expected relation between mass ratio and luminosity ratio (Popper 1978, 1980). These systems include some of the most massive eclipsing binary systems. They are all possibly contact systems. Their relative frequency among O type binaries is sufficiently great that a relatively long-lived state in the evolution of close binary systems may be involved. The purpose of this study is to examine critically the magnitude of the discrepancies between observed and predicted luminosity ratios, the latter depending on the observed mass ratios.

In § II we examine certain aspects of the distribution of mass ratios among double-lined O type binaries and list those with published mass ratios greater than 1.3. In § III we reexamine the observational material on LY Aur and NY Cep and conclude that the published mass ratios require downward revision. The discussion in § IV leads to the conclusion that it is the O type contact systems for which the discrepancy is most clearly established between the observed luminosity ratios and those predicted from the mass ratios.

In their study, Lucy and Ricco (1979) noted that the strong peak near unity in the frequency distribution of mass ratios of double-lined spectroscopic binaries is less pronounced among the O and early B systems than in later types. The small samples represented in Tables 2 (B6–M) and 4 (B0–B5) of my review of stellar masses (Popper 1980) also show the difference. The O type binaries themselves, as summarized by Garmany, Conti, and Massey (1980), show striking differences from binaries of later types in the distribution of mass ratios. In order that the sample of O type systems be comparable to the samples of later types, we consider only the 17 double-lined binaries in the compilation of Garmany, Conti, and Massey (1980) of luminosity classes III–V without striking peculiarities in their spectra. Only one of the 17 systems has Q between unity and 1.06, in striking contrast to the concentration of mass ratios close to unity shown by Lucy and Ricco (1979), while 10 systems have published values of Q greater than 1.3, a range in which a very small fraction of double-lined binaries of later classes is found. The apparently low frequency of mass ratios close to unity among double-lined O type systems is in part a consequence of the relatively low precision of velocities based on the poor lines in O type binaries. The high frequency of large mass ratios may be a consequence, in part, of the less steep dependence of luminosity on mass for the more massive stars, so that the spectrum lines of the fainter components in these systems are more readily observable. My concern is not, however, primarily with statisti-

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TABLE 1

EARLY TYPE BINARIES WITH LARGE MASS RATIOS

HD	Name	Spectrum	m_1/m_2	ΔM(obs)	ΔM_{bol}(theory): Lower Limits
		a) Nonvariable Systems			
37043 ...	ι Ori	O8.5 III	1.7	2:	1.3
48099 ...	...	O6.5 V	1.7	...	0.5
93205 ...	...	O3 V+O8:	2.6	1:	2.4
150136 ...	...	O5 III(*f*)	1.8	...	1.3
206267 ...	...	O6+O9	2.9	0.9:	2.8
		b) Eclipsing and Ellipsoidal Systems			
19820 ...	CC Cas	O9 IV	2.1	1.6:	2.4
35921 ...	LY Aur	O9.5 III	2.7[a]	0.5	3.2[a]
100213 ...	TU Mus	O7–O8	1.5	0.6	1.2
209481 ...	14 Cep[b]	O8.5 III	2.1	0.5	1.8
228854 ...	V382 Cyg	O6.5	1.4	0.4	1.0
217312 ...	NY Cep	B0 IV	2.1[a]	1.0	2.3[a]

[a]But see revised values in § III.
[b]LZ Cep.

cal matters, but rather with the systems of large mass ratio as potential violators of the relation between mass and luminosity as predicted by stellar models.

II. SYSTEMS WITH LARGE MASS RATIOS

The 10 systems referred to above with Q greater than 1.3 are listed in Table 1. They are divided into two groups of five systems each. Group (*a*) contains presumably nonvariable stars (in the geometrical sense), while group (*b*) contains known eclipsing and ellipsoidal systems. Added to this group is the detached B0 binary with shallow eclipses and large published mass ratio, NY Cep. It is the systems of the latter group to which I have called attention previously (Popper 1978, 1980).

The mass ratios and spectral types in Table 1 are taken from the compilation of Garmany, Conti, and Massey (1980) except for the mass ratio of V382 Cyg (Popper 1978) and the data for NY Cep. The apparent magnitude differences of the components in the blue region of the spectrum, ΔM(obs), are obtained from photometry of the spectrograms (references in Batten, Fletcher, and Mann 1978) except for the three eclipsing binaries LY Aur, TU Mus, and V382 Cyg, for which the magnitude differences depend as well on analyses of the light curves (LY Aur discussed in § III; TU Mus: Wilson and Rafert 1981; V382 Cyg: Bloomer, Burke, and Millis 1979). According to the photometric analyses, these three eclipsing binaries are contact systems, and the two ellipsoidal variables, CC Cas and 14 Cep are likely to be contact systems also. The components of NY Cep are well separated. The values of ΔM(obs) are to be compared with the theoretical values ΔM_{bol}(theor), due account being taken of the difference in bolometric correction between the components of a system. The theoretical values are obtained from interior models, primarily the zero-age models of Stothers (1972), Ziołkowski (1972), and Chiosi, Nasi, and Sreenivasan (1978). For the eclipsing binaries, the observationally determined masses are employed in conjunction with the models. For the noneclipsing systems, the mass of the primary component is estimated from the theoretical mass-luminosity relation and the calibration of luminosity against spectral type. Convenient tabulations are given by Straižys and Kuriliene (1981). The theoretical zero-age bolometric magnitude differences are lower limits: If the components have evolved according to theoretical tracks for single stars, with or without mass loss, the more massive star will have evolved in luminosity more than the less massive, and the difference in absolute magnitudes should be greater than for unevolved stars. This matter is discussed further in § IV for the more critical systems.

The principal concern in this investigation is the difference, for each system, between the last two columns of Table 1, with allowance for the difference in bolometric corrections of the two components. After reexamining the observational material for LY Aur and NY Cep in § III, it is concluded in § IV that only the three probable contact systems LY Aur, V382 Cyg, and 14 Cep are shown clearly to violate the theoretical predictions, and that TU Mus, also a contact system, may also do so. For the other systems, the evidence is not adequate for a decision. Although the discrepancies for the contact O type binaries are not so great as for the W UMa systems, the existence of this relatively large group, including all of the well-analyzed O type eclipsing binaries, calls for theoretical explanation.

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III. LY AURIGAE AND NY CEPHEI

a) *LY Aurigae*

Three independent series of spectrograms have been obtained of LY Aur, all within the interval 1968–1972 and each with approximately 30 spectrograms showing double lines. The results from measurement of my spectrograms, obtained at the Lick Observatory, are in such good agreement with those obtained at Victoria and analyzed by Andersen, Batten, and Hilditch (1974) that the publication of the Lick results has had low priority.

The third set of observations is that obtained at Asiago by Margoni, Stagni, and Mammano (1981). Their values of the amplitudes of velocity variations K_1 and K_2 (160,270) differ greatly from those obtained by Andersen *et al.* (113,302) and by me (114,307; but see below). The Asiago prismatic spectrograms are of comparatively low dispersion (42 Å mm^{-1} at Hγ compared to 10–15 Å mm^{-1} for most of the Victoria plates and 16 Å mm^{-1} at Lick) and narrow (0.35 mm compared to 0.85 mm at Lick). Furthermore, the Asiago list of lines measured for radial velocity contains a number of surprises. As examples, low-excitation lines of Ca II, Mg II, and Si II are listed for this system of type 09.5; the weak line of He I at λ4024.0 is said to be measured in both components separately from the nearby strong He I line at λ4026.1; and the He II lines of the Pickering series are said to be measured separately from the nearly coincident Balmer lines of hydrogen. Additionally, their list of "Petrie's lines" is based on their presence in a table of standard lines for velocity work rather than on their strength, resolution of components, and certainty of presence in the spectrum. For these reasons, the Asiago material will not, reluctantly, be included in further discussion.

It has become clear, in spite of the excellent agreement between the Lick and Victoria velocities, that this system merits further scrutiny. The large mass ratio, 2.7, obtained by Andersen, Batten, and Hilditch (1974) and by me and adopted by Garmany, Conti, and Massey (1980), has been questioned on two grounds. Andersen *et al.* note that the asymmetry of the He I lines, in particular, of the more luminous, more massive component, might be a consequence of blending with lines of the visual companion, ADS 4072B. If that is the case, the true value of K_1 is greater than that measured (Andersen *et al.* give 175 km s^{-1} as a minimum value, corrected from 113). Second, in his comprehensive analysis of the available photometric material, Eaton (1978) was unable to obtain a reasonable photometric solution employing the large published spectroscopic mass ratio. Hence, interpretation of the velocities of the more luminous component of LY Aur needs to be reexamined.

Tracings of the λ4471 region in the spectrum of LY Aur, showing the asymmetry referred to above, all based on observations made near the same orbital phase, have been reproduced by Andersen, Batten, and Hilditch (1974) and, with considerably lower dispersion, in a survey of the spectra of OB eclipsing binaries (Popper 1981). To show the variation of the asymmetry with phase, tracings of spectrograms of the He I 4471.5 and Si IV 4088.9 regions, based on a plate taken near each nodal passage, are shown in Figure 1. When positively displaced, the Si IV line blends badly with the negatively displaced component of N III 4097.3 and does not give usable velocities. The features that may be attributed to lines in the spectrum of ADS 4072B, which is 0″.6 distant from and roughly 1.5 mag fainter than the eclipsing binary, are indicated. If the magnitude difference between the components in LY Aur itself is 0.7 mag, for example, ADS 4072B is only about 0.35 mag fainter than the secondary of LY Aur. If B is a physical companion, it would also be expected to be a late O or early B star. Thus, it is reasonable to suppose that the sharper features shown in the tracings near zero velocity are contributed by the visual companion, and that the velocities measured by Andersen, Batten, and Hilditch (1974) and by me, attributed to the primary component, are systematically in error, leading to masses that are too small and a mass ratio that is too large. This interpretation of the measurement, while discussed by Andersen *et al.*, was considered by them to be less likely than the interpretation leading to the smaller masses and large mass ratio. It should be pointed out that the tracings reproduced by Andersen *et al.* and in this paper are taken from plates having the IIIa-J emulsion, with high signal-to-noise ratio. Four of the plates of the Victoria series are on IIIa-J, while 11 of my 29 are, the remainder being on IIa-O. In general, it is only on my IIIa-J plates that the sharper lines, attributed here to ADS 4072B, are as well resolved as shown in Figure 1.

Measurement of the velocities from these sharper features is uncertain because of blending with the lines of the primary of LY Aur. The mean velocity obtained from measurement of 15 lines on five IIIa-J plates exposed near phase 0.25 (velocity of primary component negative) is -8 ± 6 km s^{-1}. The corresponding velocity from 17 lines on four IIIa-J plates near the other node is $+34 \pm 4$ km s^{-1}. The closeness of these values to the nearly zero systemic velocity of LY Aur, in spite of their blending, lends support to the hypothesis that these lines arise in the spectrum of ADS 4072B.

Table 2 contains several solutions for the spectrographic elements of LY Aur. The agreement between the Victoria and Lick results is excellent. The three values of K for the primary obtained from the Lick plates may be understood by referring to Figure 1. The difference between the values of K_1 obtained from measures of the He I lines, including the feature attributed to ADS 4072B, and the value obtained from the lines of higher excitation appears to be a consequence of that feature

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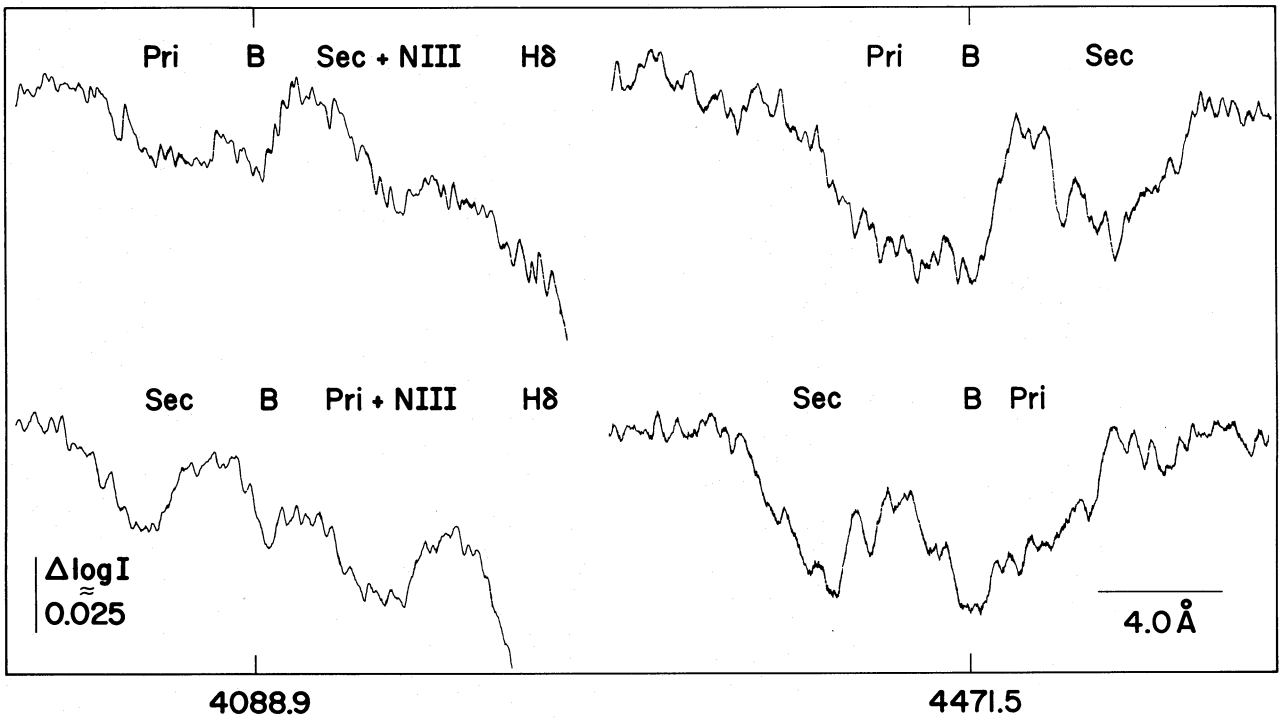

FIG. 1.—Si IV 4088.9 and He I 4471.5 in the spectrum of LY Aur. *Above*, 0.275 phase; *below*, 0.816 phase; phases measured from primary minimum. Features designated "B" are attributed to ADS 4072B. "N III" refers to the line at 4097.3 Å. Only the shortward edge of the profile of Hδ is shown.

TABLE 2

CIRCULAR ORBITS FOR LY AURIGAE

	Primary		Secondary	
Solution	K (km s^{-1})	V_o (km s^{-1})	K (km s^{-1})	V_o (km s^{-1})
Andersen *et al.* (1974):				
He I lines	113.0 ±5.9	−2.5 ±3.1	301.7 ±5.9	(−2.5)
This study:				
He I lines	108.4 ±3.0	+3.0 ±2.9	300.7 ±3.2	−4.6 ±3.0
Si IV + He II	138.3 ±3.0	+9.6 ±2.8	305.3 ±3.3	−0.9 ±3.0
ADS 4072B avoided	199 ±7	+11 ±8	...	...
Adopted	200 ±25	(−3) ...	302 ±3	−3 ±2

being relatively weaker in the lines of higher excitation (e.g., λ4088) than in the lines of lower excitation (e.g., λ4471), presumably because of the slightly later type of the visual companion. The value 199 for K_1 is based on attempts to measure that part of the line profile attributed to the primary component of LY Aur, avoiding the feature attributed to ADS 4072B (see Fig. 1). This measurement was carried out on 33 lines on 14 IIIa-J plates. The adopted value of K_1, 200 km s^{-1}, must be considered only a crude estimate. A lower limit for this quantity was estimated by Andersen, Batten, and Hilditch (1974) from two plates at the same phase to be 175 km s^{-1}.

The mass ratio in the adopted solution of Table 2, 1.5, is close to the value 1.7 obtained by Eaton (1978) on the assumption that LY Aur is a contact system. It should be noted, as emphasized by Eaton, that considerable uncertainty is present in the photometric solution be-

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TABLE 3

THE COMPONENTS OF LY AURIGAE

Component	$m(m_\odot)$	$R(R_\odot)$	$\log T_e$	$\log L$	M_v
Primary	31.6±3.2	16.4±2.0	4.514±0.023	5.43±0.15	−5.7±0.3
Secondary.....	21.0±4.7	13.4±1.6	4.486±0.023	5.16±0.15	−5.2±0.3

cause, among other reasons, of the poorly determined contribution of ADS 7042B to the light of the system. Within the uncertainties of both the spectrographic and photometric analyses, we appear to have a reasonably consistent picture of LY Aur as a contact system. The properties of its components differ considerably, according to the present model, from those given in Table 5 of Popper (1980). A revised set is given in Table 3 of this paper. The photometric radii adopted are those for a contact system with a mass ratio of 1.5. Eaton's temperature ratio is adopted. It is dependent on the flux ratio shown by the light curve. The mean temperature, 32,000 K, is close to the value for type O9.5 in both Böhm-Vitense's scale (1981) and in mine (Popper 1980). Eaton's solution is preferred to the rather similar solution of Cester *et al.* (1978) since, although the latter authors also conclude that LY Aur is a contact system, their analysis with Wood's triaxial model does not constrain the system to have a contact configuration and employs the old mass ratio, here considered to be incorrect.

b) NY Cephei

NY Cephei (HD 207312) is an early B-type binary in a highly eccentric orbit with a period of $15^{d}.3$ and a shallow eclipse near periastron passage (Barlow and Forbes 1980 and references in Batten, Fletcher, and Mann 1978). Although my two Lick spectrograms, with a scale of 16 Å mm^{-1} and 0.66 mm width, show He II 4686 in absorption, this line is probably not sufficiently strong to require a classification earlier than that published, B0 IV. The published values for the minimum masses of the components of NY Cep, 27 and 13 $m_\odot$, are based on prismatic spectrograms with a scale of 33 Å mm^{-1} at Hγ, on 18 of which H and He lines of the secondary were measured (Heard and Fernie 1968). The velocities of the primary component from my two spectrograms agree well with those predicted from the orbital elements of Heard and Fernie. On the other hand, while the presence of lines of the secondary is indicated on my plate observed near the phase of maximum orbital velocity, its hydrogen lines are seen only as asymmetric wings, and its helium lines are too badly blended with the strong lines of the primary to yield velocities in which any confidence can be placed. A tracing of a portion of this spectrogram, showing the effects referred to, has been published (Popper 1981). An attempt to measure lines of the unresolved secondary leads me to the uncertain conclusion that K_2 probably lies between 140 and 190 km s^{-1}, compared to the published value 228. With this range of values of K_2, the mass of the primary component would lie between 9 and 18 $m_\odot$, compared to the published value, 27 $m_\odot$. The overestimation of masses that results from attempts at visual measurement of unresolved lines is characteristic (e.g., EO Aur, Popper 1978; HD 208095, Popper 1982), and probably is a consequence, at least in part, of interpreting the protruding portion of a poorly resolved fainter component as being the line itself. In the light of these circumstances, the difference between the values of the systemic velocity found for the two components of NY Cep by Heard and Fernie (1968) is not significant.

Further evidence of a circumstantial nature can be brought to bear on the problem of the masses in NY Cep. This binary is a member of the III Cep association (as discussed by Fernie 1973), its components having $M_{\rm bol}$ −6.2 and −5.2. Less than 1° from NY Cep is the double-lined B0 eclipsing binary, CW Cep, also a member of III Cep, of nearly the same luminosity, $M_{\rm bol}$ −6.2 and −5.6, and masses 11.8 and 11.1 $m_\odot$ (Popper 1980, Table 4). The components of both systems lie on the well-defined main sequence of the association (Crawford and Barnes 1970; Garrison 1970). If the primary of NY Cep had a mass of 27 $m_\odot$, it would be very anomalous, not only with respect to CW Cep but also with respect to the tight relation between mass and luminosity prevailing for all detached systems with well-established properties (e.g., Popper 1980). In short, the masses and mass ratio in NY Cep are poorly known, and no violation of the theoretical relation between mass ratio and luminosity ratio can be attributed to this system. My guess at the masses is a very uncertain 12 and 8 $m_\odot$.

IV. DISCUSSION

In this section we attempt to answer the principal question raised in this paper: Which system in Table 1, given their mass ratios, violate in their luminosity ratios predictions from theory for single stars? This question is more difficult to answer with confidence for O type systems than for later types for two principal reasons. First, because of the strong dependence of bolometric correction and temperature on spectral type, the conversion from observed to bolometric ratio requires that the types of the components of noneclipsing systems, in particular, be well determined—a difficult task if, as in

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most of our systems, the lines of one component are visible only with difficulty. In the case of an eclipsing binary with two well-defined minima, the difference in bolometric corrections can be determined from a calibration in terms of surface flux. Second, because of the less strong dependence of luminosity upon mass than in less massive stars, a given uncertainty in the luminosity ratio corresponds to a larger range of mass ratios, which are themselves generally less well determined among the O type binaries, a consequence of the generally poor quality of the lines in the spectra of O type binaries. In the following discussions of individual systems, references are not, in general, given since they may be found in § II.

ι Orionis.—The spectrum of the secondary is so weak that not only is the mass ratio uncertain, but so also are the luminosity ratio and difference in spectral type. The latter is required in order to obtain both the value of $\Delta M_{\rm bol}$(theor) from the models and the value of $\Delta M_{\rm bol}$(obs) from ΔM(obs). Hence, no discrepancy is clearly established.

HD 48099.—For the large masses predicted for stars as hot as those in this system, the slope of the mass-luminosity relation is particularly low. In addition, the small values of the velocity amplitudes given by Garmany, Conti, and Massey (1980), 55 and 92 km s^{-1}, imply very badly blended line profiles and an uncertain mass ratio.

HD 93205.—The difference in bolometric correction between types O3 and O8 can readily account for the difference between the quite uncertain values of ΔM(obs) and $\Delta M_{\rm bol}$(theor).

HD 150136.—Insufficient information is available on the magnitude difference between the components, which is considerable (C. D. Garmany, private communication), and about the difference in spectral types to reach a conclusion about a true discrepancy.

HD 206267.—As may be concluded from examination of profiles of lines in this system published by Crampton and Redman (1975), the values of the magnitude difference, of the difference in spectral type, and of K_2 are all quite uncertain. If the mass ratio really differs as greatly from unity as the published value, the difference between observed and predicted luminosity ratio may, indeed, be significant.

CC Cassiopeiae.—As in the case of ι Ori, the mass ratio, luminosity ratio, and difference in spectral type are very uncertain because of the weakness of the lines of the secondary component. Hence, no clear discrepancy is established.

The systems of Table 1(*a*) as well as CC Cas and NY Cep will not be considered further. We turn now to the remaining four systems of Table 1(*b*). The sources of the mass ratios in TU Mus, 14 Cep, and V382 Cyg are referred to in § II. The mass ratio of LY Aur is discussed in § III. Tracings of spectrograms, helpful in judging the reliability of the mass ratios, are available for these four systems—LY Aur in Andersen, Batten, and Hilditch (1974), in Popper (1981), and in this paper (Figure 1); TU Mus in Andersen and Grønbech (1975); 14 Cep in this paper (Fig. 2); and V382 Cyg in Popper (1978, 1981). While the profiles of the He lines, which play a major role in the mass determinations, are not completely resolved in any of the four systems, the degree of overlap is not appreciably greater than in most of the OB binaries for which masses have been published (see Popper 1981). The effect of the larger ratio of rotational velocity to orbital velocity (or line separation) in the four contact O type systems than in later B type systems is compensated by the smaller ratio of width of damping wings to line separation in the hotter stars. Hence, while the published masses of all these systems are probably systematically smaller than the true masses, their mass ratios may be approximately correct.

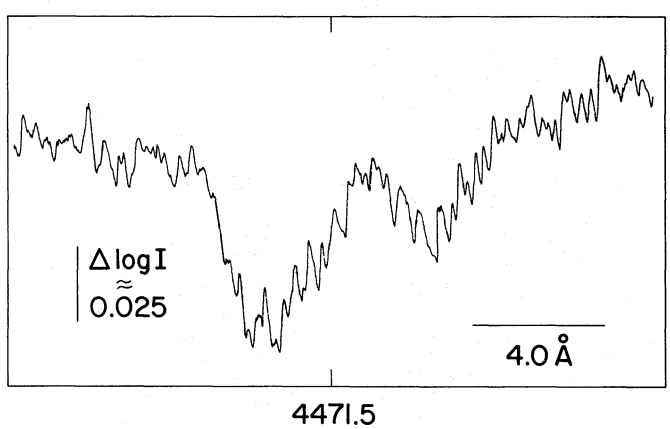

FIG. 2.—He I 4471.5 in the spectrum of 14 Cep. According to the orbit of Hilditch (1974), the separation of the components is 296 km s^{-1}.

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The magnitude differences in these four systems obtained from observations, ΔM(obs), are listed in Table 1. Here we give more detail on their determination and discuss the conversions to $\Delta M_{\rm bol}$(obs). The results for LY Aur are in Table 3, $\Delta M_{\rm bol}(\rm obs) = 0.68$. The magnitude difference of the components of TU Mus obtained by Wilson and Rafert (1981) in their photometric solution, $\Delta M(\rm obs) = 0.58$, is in good agreement with the value 0.62 obtained from the strengths of lines in the spectrum by Andersen and Grønbech (1975). The surface brightness ratio, 1.23, obtained from Wilson and Rafert's solution, corresponds to a difference in bolometric correction (see Popper 1980, Table 1) of 0.37 mag. Hence, the bolometric magnitude difference, $\Delta M_{\rm bol}$(obs), is 0.95. The temperatures at spectral type O8 corresponding to the given surface brightness ratio are 37,800 K and 33,100 K. The smaller difference, $\Delta M_{\rm bol}(\rm obs) = 0.45$, given for TU Mus in my review (Popper 1980, Table 5) is a result of mistakenly adopting too small a temperature difference between the components. The corrected values of log L are 5.00 and 4.62. For V382 Cyg, the magnitude difference from analysis of the light curve by Bloomer, Burke, and Millis (1979), $\Delta M(\rm obs) = 0.44$, is in good agreement with the unpublished value, 0.36 mag, obtained from my spectrograms. The surface-brightness ratio obtained by Bloomer *et al.* is close to unity, so the difference in bolometric corrections is small. We may adopt $\Delta M_{\rm bol}(\rm obs) = 0.45$. In the case of 14 Cep, we have no sound basis for converting the spectroscopic magnitude difference, 0.48 (Petrie 1962), to a bolometric difference. Both Petrie and Hilditch (1974) state that the two components are quite similar in spectral type. In order not to underestimate the true luminosity difference, I assume a difference in bolometric correction of 0.3 mag, giving $\Delta M_{\rm bol}(\rm obs) = 0.8$. The values of $\Delta M_{\rm bol}$(obs) are listed in Table 4.

The final step in this discussion is the determination of the values of $\Delta M_{\rm bol}$(theor) for the four systems. As noted in § II, the lower limit to this quantity for each system is derived from zero-age models for the given masses. While the luminosities themselves are somewhat dependent on details of the models and on the assumed chemical composition, the luminosity ratios are not sensitive to these details, at least to the precision with which we are concerned. A useful tabulation for $X = 0.70$, $Z = 0.02$–0.03 is given by Straižys and Kuriliene (1981). The zero-age values of $\Delta M_{\rm bol}$(theor) are lower limits since the rate of evolution in luminosity of a single star increases with mass. Rough upper limits to the values of $\Delta M_{\rm bol}$(theor) may be obtained from evolutionary models for single stars without mass loss, in which the star of lower mass is unevolved, while the higher mass component has just reached the end of core hydrogen burning. Over the range of masses we are concerned with, 15–30 $m_\odot$, the amount of evolution in luminosity to the end of core hydrogen burning is close to 0.7 mag, a value nearly independent of mass according to a number of calculations (Iben 1966, 16 $m_\odot$; Chiosi and Summa 1970, 20 and 30 $m_\odot$; Barbaro, Chiosi, and Nobilis 1971, 15 and 20 $m_\odot$). The time for this evolutionary development is about 10^7 yr for 15 $m_\odot$ and 4×10^6 yr for 30 $m_\odot$. Thereafter, evolution in luminosity is relatively slight.

Results for the four binaries in question are given in Table 4. The mass given for the primary component of the ellipsoidal variable, 14 Cep, is estimated from the luminosity as derived from its spectral type, O8.5 III. The values of $M_{\rm bol}$(obs) for the eclipsing systems are obtained from the radii and effective temperatures, while the values of $M_{\rm bol}$(ZAMS) are taken from the models for the listed masses. A rough estimate of the uncertainty in the values of $\Delta M_{\rm bol}$(obs) is ± 0.3 mag, although the uncertainties of the individual values of $M_{\rm bol}$ may be greater. The two values given for $\Delta M_{\rm bol}$(theor) are the lower [$\Delta M_{\rm bol}$(ZAMS)] and upper [$\Delta M_{\rm bol}(\rm ZAMS) + 0.7$] limits discussed above. Inclusion in the models of the effects of mass loss due to stellar winds, now generally recognized to be an important effect in the more luminous O stars (e.g., Lamers 1981), slows the rate of evolution. If the rate of mass loss is positively correlated with mass and luminosity, the effect will be to decrease, for a given age, the value of $\Delta M_{\rm bol}$(theor) below the value obtained for constant mass, leading to values intermediate between those given

TABLE 4

OBSERVED AND THEORETICAL MAGNITUDE DIFFERENCES

	Mass($m_\odot$)		$M_{\rm bol}$(obs)		$M_{\rm bol}$(ZAMS)			$\Delta M_{\rm bol}$(theor.)	
Object	Pri.	Sec.	Pri.	Sec.	Pri.	Sec.	$\Delta M_{\rm bol}$(obs)	$\Delta M_{\rm bol}$(ZAMS)	$\Delta M_{\rm bol}$(ZAMS) +0.7
LY Aur	31.6 ±3.2	21.0 ±4.7	−8.9	−8.2	−8.1	−7.0	0.7	1.1	1.8
TU Mus.....	23.8 ±2.5	15.8 ±1.5	−7.8	−6.8	−7.4	−6.2	1.0	1.2	1.9
V382 Cyg.....	26.9 ±2.7	19.0 ±1.9	−8.2	−7.7	−7.7	−6.7	0.5	1.0	1.7
14 Cep	35:	16.5:	...	...	−8.1	−6.3	0.8	1.8	2.5

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in the last two columns of Table 4. This conclusion has been verified with the aid of the models including mass loss calculated by de Loore, De Grève, and Vanbeveren (1978).

The principal result of this analysis is the difference for each of the four systems of Table 4 between the observed and theoretical values of $\Delta M_{\rm bol}$, the latter being based on the masses. We see that, for each of the four systems the stars differ less in luminosity than predicted, a discrepancy in the same sense as for contact systems of low mass, the W UMa binaries. The discrepancy is not well established for TU Mus if both components are unevolved.

The luminosities of the components, probably in contact, in the three O type eclipsing systems, LY Aur, TU Mus, and V382 Cyg, are between 0.4 and 1 mag greater than predicted by the zero-age models for stars of the same mass. It is reasonable to conclude that these stars have evolved into contact systems, with or without mass exchange and mass loss. These three systems are the most massive binaries with well-established properties. It is unfortunate that there are no clearly detached O type binaries, with properties as well established as those of the three eclipsing systems, to serve as a basis for judging the extent to which the disagreement between observation and theory, summarized in Table 4, is dependent on the contact nature of the systems. The properties of detached noneclipsing O type systems, including those listed in Table 1(*a*), if they are, in fact, detached, are too poorly known to serve as a basis for comparison. The earliest detached system with reasonably well established properties and with components differing appreciably in mass is V453 Cyg, B0.5 (Popper 1980, Table 4). In this case the observed magnitude difference is 0.4 mag *greater* than predicted for unevolved stars, and differences in evolution between the components would decrease the difference in luminosity, leaving little or no discrepancy.

V. CONCLUSION

LY Aur, V382 Cyg, and 14 Cep are O type binaries with components apparently in contact configurations, and in which the luminosity ratios of the components are closer to unity than predicted from the mass ratios. The results are summarized in Table 4. The data for LY Aur are based on a rediscussion of the spectrographic material on this system in conjunction with Eaton's (1978) analysis of the photometry. The discrepancy is not so clearly established for the contact system TU Mus. The large values of the published masses and mass ratio in the detached B0 system NY Cep are found to have been based on attempts to measure unresolved lines.

In this study the focus has been on possible disagreement between theory and observation for the best observed O type binaries with respect to their mass and luminosity ratios. Disagreements are found among what appear to be contact systems. In their discussion of contact systems of type O, Leung and Schneider (1979) were apparently not aware of these systems. The three binaries discussed by them are not included in our Table 1, partly because published mass ratios, Q, are less than 1.3 (AO Cas, UW CMa), but primarily because spectroscopic complications and difficulties in reconciling photometric and spectroscopic analyses make the interpretation of the measured velocities and mass ratios uncertain (Leung and Schneider 1978*a*, *b*; Schneider and Leung 1978). These investigations, together with the results of this paper, make it appear that contact systems are not uncommon among the more massive binaries. On the basis of this limited information, the contact configuration is a comparatively stable one. It is not surprising that massive close binaries should evolve rapidly into configurations with one component filling its Roche lobe. Perhaps the most significant result requiring theoretical explanation is that the contact configuration among O type binaries is encountered with greater frequency than the semidetached configuration, which is conspicuous among systems of lower mass. Along with the explanation of the frequency of contact systems may come an understanding of the principal result of this investigation—the difference in the observed mass-luminosity relation within contact systems with components of masses 15–30 $m_\odot$ from the predicted relation. Some aspects of the interpretation of early-type contact systems have been discussed by Lucy and Wilson (1979).

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