

REDISCUSSION OF ECLIPSING BINARIES. I. Z HERCULIS*

DANIEL M. POPPER

Department of Astronomy, University of California, Los Angeles

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ABSTRACT

Z Herculis is removed from the group of stars showing major discrepancies between published photometric and spectrographic analyses by means of new photoelectric and spectrographic data. The importance is emphasized of carrying out photoelectric observations in at least two colors simultaneously on a color system, preferably the U , B , V system, which is well calibrated against spectral type. The use of spectrograms in the visual region of the spectrum has proved advantageous.

The principal properties of the two components of the system are given in the accompanying table

$B-V$	+0 47	+0 91	Luminosity (solar units)	4 7	2 8
Radius (solar units)	1 6	2 6	M_v	+2.9	+3.8
Mass (solar units)	1 22	1 10	Spectral type	F4 IV-V	K0 IV

The properties of each star lie within the range of those of other stars of similar type. At least one component of the system shows slow intrinsic variations.

INTRODUCTION

Z Her¹ is an eclipsing variable of the seventh magnitude, with an F-type spectrum, partial eclipses, and period very close to 4 days. The existing spectrographic orbit dates from 1919 (Adams and Joy 1919). Baglow (1952) has published a two-color photoelectric study of the light-curve. Analysis of the system has remained in an unsatisfactory state principally because of uncertainty concerning the nature of the fainter, cooler component. According to published descriptions of the spectrum, it is an F-type star, whereas from the depths of minima, according to Baglow, it is of type K or M. This kind of discrepancy is of fairly common occurrence (e.g., Wyse 1934). It has seemed worthwhile to obtain new data in an attempt to clarify the matter.

The present study of Z Her is based on new spectrograms obtained at the McDonald, Lick, and Mount Wilson Observatories and on a two-color photoelectric light-curve obtained at Lick, supplemented by a few observations at McDonald. My light-curves are similar to those of Baglow, but the treatment differs in several respects.

SPECTROGRAPHIC DATA

Figure 1 shows the photographic region of the spectrum of Z Her near one node, when the brighter component is receding (McDonald spectrogram, original dispersion 26 Å/mm at $H\gamma$). A spectrogram of α CMi, spectrum F5 IV-V, is shown for comparison. Although there is evidence of a second component in the spectrum of Z Her, e.g., at $H\delta$, λ 4226, λ 4271, $H\gamma$, none of its lines appear free of serious blending with lines of the brighter component. Careful examination of Mount Wilson coude plates of this region of the spectrum only accentuates the difficulty. It is clear that a reliable spectral type of the fainter component cannot be obtained from such plates and that radial velocities of this component must be treated with caution.

At the time of mid-primary eclipse the fainter component of Z Her contributes 60

* This investigation was made possible in part by a co-operative arrangement with the Mount Wilson and Palomar Observatories

¹ HD 163930, var ; F5p; α_{1900} 17^h53^m6; δ_{1900} + 15°9'.

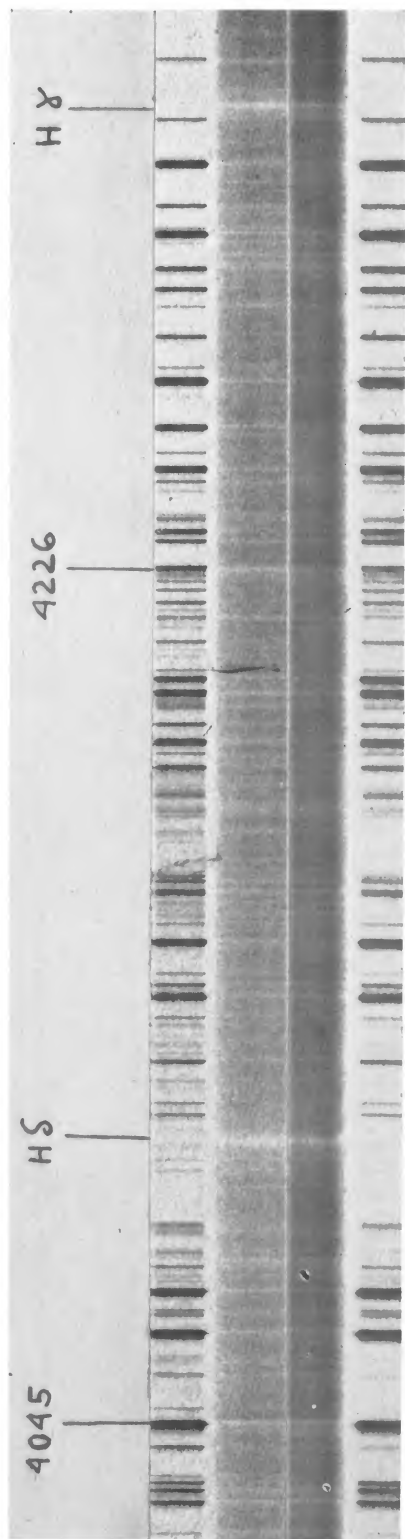


FIG. 1.—*Above:* α CMi; *below:* Z Herculis, 0.80 phase. McDonald Observatory spectrograms



FIG. 2.—D lines in Z Herculis, 0.09 phase. Mount Wilson coude spectrogram

per cent of the light of the system in the photographic region. A weak spectrogram obtained for me at Mount Hamilton near the time of mid-primary eclipse in the summer of 1951 by William Wehlau shows λ 4226 and the G band definitely strengthened, indicating a combined spectral type in the vicinity of G5. Figure 2 shows the region of the D lines on a coude spectrogram. Although the cooler star (longward displacement) is nearly 1 mag. fainter than the hotter star in this region of the spectrum, the D lines are of approximately equal intensity, those of the cooler star being broader. This is confirming evidence that the cooler star is considerably later in type, since the D lines strengthen greatly and broaden from type F to type K.

Thus the evidence is that the secondary component is considerably cooler than the primary, but no reliable evaluation of its spectral type can be obtained from the spectrograms. It will be seen in the discussion of the photometric data that the color, surface brightness, and luminosity of this component place it at spectral type K0 IV. My estimate of the spectral type of the primary component on McDonald spectrograms is F4. Miss Roman (1956) gives F6 V for the composite spectrum at maximum light.

TABLE 1
COUDÉ VELOCITIES OF Z HERCULIS

PLATE CE	U T.	PHASE	VELOCITIES (km/sec)			RESIDUALS (O-C) (km/sec)		
			V_1	$V_2(\text{Abs})$	$V_2(\text{Em})$	V_1	$V_2(\text{Abs})$	$V_2(\text{Em})$
	1954							
9168	Apr 10 44	0 ^h 954	- 21 6		- 76	+0 7		-3
9272	June 13 38	968	- 27 3		- 70	+2 1		-5
9276	June 14 33	207	-127 1	+ 38	+ 51	-0 6	- 6	+7
9388	Sept 16 18	711	+ 35 9	-126	-136	+1 1	+10	0
	1955							
9796	May 3 34	106	- 96 4	+ 6		+1 2	- 5	
9845	June 11 29	860	+ 14 9	-127		-3 2	- 9	
9849	June 12 22	094	- 92 2	+ 3		+0 4	- 3	
9853	June 13 23	347	-116 0	+ 31	+ 38	-1 5	+ 1	+8
10022	Sept 3 17	0 867	+ 15 8	-119	-114	0	- 4	+1

The only lines in the photographic region of the spectrum belonging to the cooler component that are definitely unblended are the emission lines of H and K discovered by Hiltner (1947). To put the radial-velocity determinations of this component on a firm basis, recourse was had to the visual region of the spectrum where the cooler component is relatively brighter and where few strong lines are present to cause blending difficulties (see Fig. 2). A new spectrographic orbit has been determined from coude spectrograms alone by using principally the photographic region of the spectrum for the brighter component and the visual region plus H and K emission for the fainter. The emission lines, being diffuse, are relatively difficult to measure.

Table 1 lists the coude observations. The phases are obtained from the light-elements discussed later. From these velocities the circular elements of Table 2 have been computed. Since the differences between absorption and emission velocities are probably not significant, the adopted value of K_2 is a weighted mean. Figure 3 shows the coude velocities and the curves given by the adopted elements, from which the residuals of Table 1 have been computed.

From the elements in Table 2 we obtain

$$a \sin i = 14.0 \text{ solar radii}, \quad M_1 \sin^3 i = 1.20, \quad M_2 \sin^3 i = 1.08,$$

where a is the radius of the relative orbit, i is the orbital inclination, and the masses, $\mathcal{M}$, are in solar units. The more massive star is brighter and is eclipsed at zero phase; that is, it is the hotter star.

The evidence from Z Her lends support to Eggen's (1955) conjecture that the H and K emission lines in subgiant components of eclipsing binaries show the same velocity amplitude as the corresponding absorption lines. Revisions of the spectral types of the cooler component of Z Her and of the components of AW Her (Popper 1956), plus new material on VV Mon, strengthen the tentative conclusion that strong emission lines at H and K appear in the spectra of subgiant components of eclipsing binaries only near type K0.

TABLE 2
ELEMENTS OF THE VELOCITY-CURVES

	Absorption	Emission	Adopted	Adams and Joy
K_1 (km/sec)	83.4 ± 0.6 (p.e.)	97.7 ± 1.6 (p.e.)	+83.4	+88.2
K_2 (km/sec)	91.0 ± 2.1	-44.4 ± 1.2	+93.0	+101.8
γ (km/sec)	-46.1 ± 0.4		-46.1	-46.5
P (assumed)	3 993 days			

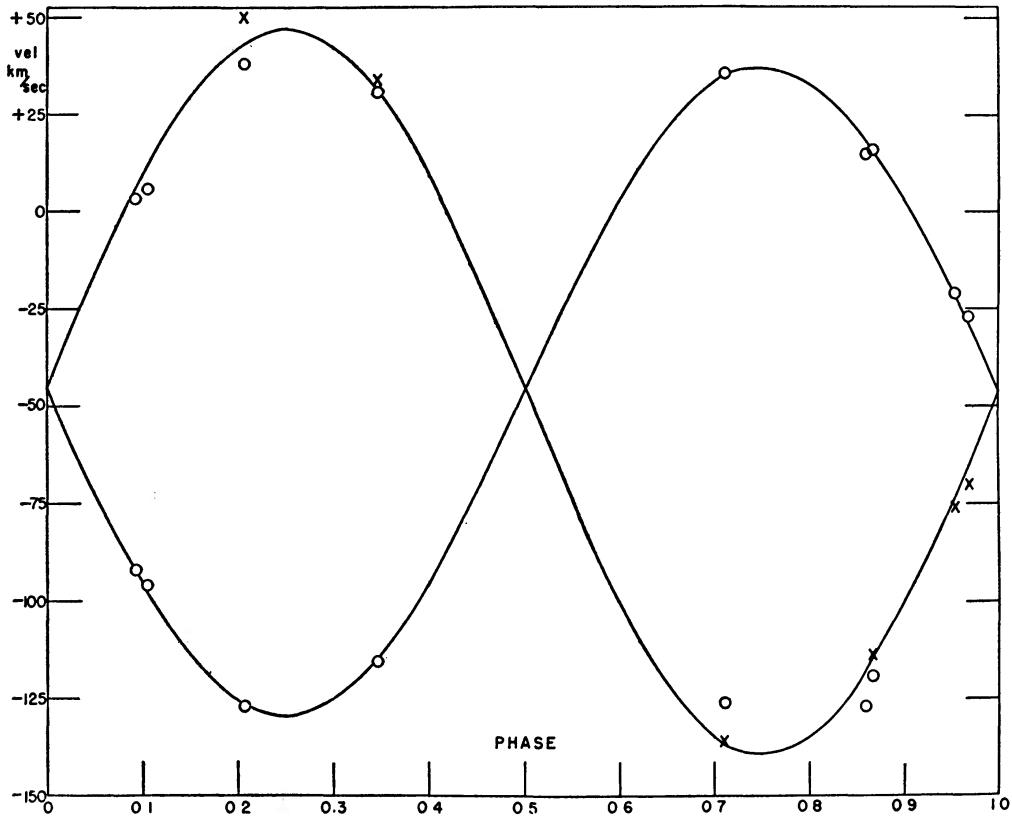


FIG. 3.—Coudé velocities of Z Herculis. Circles: absorption lines; crosses: emission lines. The hotter, brighter star has velocities of approach after zero phase.

If the periods of axial rotation and orbital revolution of the larger star are equal, the range of equatorial velocities computed from the period and radius of the star is 64 km/sec. The measured widths of the emission lines correspond to a velocity spread of about 50 km/sec. Sanford (1951) found a similar ratio of observed to predicted emission-line widths for the components of AR Lac.

PHOTOMETRIC DATA

Photometric observations of Z Her in two colors, very nearly on the B, V system, were obtained on 25 nights from July 10 through September 3, 1951, with a photoelectric photometer on the 12-inch refractor at the Lick Observatory. This instrument, which employed a 1P21 photomultiplier, linear amplifier, and recording potentiometer, is described by Weaver (1952). A few additional observations were obtained in August, 1953, with a similar photometer on the 13-inch reflector at the McDonald Observatory. The observing technique has been mentioned previously (Popper 1955). The comparison star was HD 164043.² Its magnitude and color are $V = 7.18$ and $B - V = +0.53$. This comparison star was also used by Baglow (1952) in his two-color study of Z Her in May and early June of the same year, so that the two sets of observations are quite similar and can be discussed together conveniently. Corrections for differential extinction rarely amounted to as much as 0.003 mag.

Because the period of Z Her equals very nearly 4 days, only four sections of the light-curve can be observed from a single station in one observing season. In the 1951 season in the western United States those sections included parts of the eclipses. Figures 4, 5, and 6 show the photometric observations. The unit of light in all cases is the light of the comparison star.

Times of Minima

Primary eclipse was observed on 5 nights, secondary eclipse on 6 nights. On 3 of the 5 nights, primary minimum was observed well past mid-eclipse (*crosses* in Fig. 5), a phase not quite reached by Baglow. My date of primary minimum is $\text{JD}_{\text{helioe}} 2433852.9058 \pm 0.0002$ (estimated), 0.0140 day later than predicted by the elements in the *General Catalogue of Variable Stars* and 0.0035 day earlier than Baglow had estimated. The period of Z Her has been suspected of variability. All phases used in this paper are expressed in fractions of a period after primary minimum, the dates of which have been computed from the light-elements,

$$\text{JD}_{\text{helioe}} = 2433852.9058 + 3.99280E.$$

Although secondary minimum was observed beyond predicted mid-eclipse on 5 nights, the rise in brightness (*crosses* in Fig. 6) is insufficient to determine whether a slight displacement of secondary minimum is present.

Light-Curve between Minima

Analysis of the light-curve between minima is hampered by a lack of sufficient points, essentially four being obtained in a season. The observations, shown in Figure 4, are summarized in Table 3. Baglow's observations are given for comparison, as are some observations made at McDonald in 1953. It is clear that the light-curve undergoes slow changes, as indicated by the observations near phases 0.25 and 0.75. The effect is best shown by the magnitude differences (mean of two colors), phase 0.75 *minus* phase 0.25: Baglow, May, 1951, -0.005 mag.; Lick, July–August, 1951, -0.020 mag.; McDonald, August, 1953, $+0.024$ mag. Examination of the data in Table 3 leads to the conclusion that the differences are due to *increases* in brightness near 0.75 phase (Lick 1951) or 0.25 phase (McDonald 1953) rather than to decreases at the opposite phases. As may be seen

² HD164043, 7 1; F8; $\alpha_{1900} 17^{\text{h}}54^{\text{m}}2$; $\delta_{1900} + 14^{\circ}52'$

in Figure 4, during the Lick and McDonald observations the differences repeat so well from revolution to revolution that there can be no doubt as to their reality. One is reminded of the variations in the case of AR Lac (Wood 1946; Kron 1947), which is a system somewhat resembling Z Her. The observations are inadequate to determine which component of the system of Z Her is responsible for the variations.

Because of the small number of points between minima and because of the variations in the light-curve, rectification constants may not be evaluated in the usual way. On the

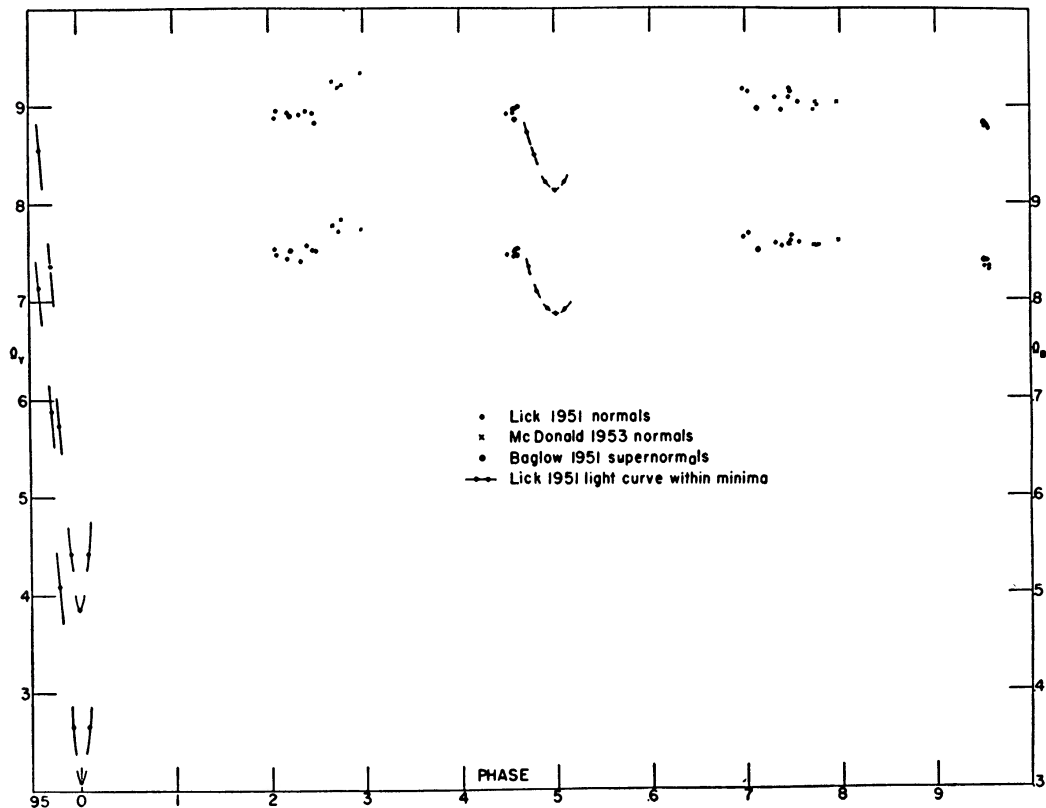


FIG. 4.—Photoelectric observations of Z Herculis. Above: yellow; below: blue. The unit of ordinates is the light of the comparison star.

TABLE 3*
LIGHT OF Z HERCULIS OUTSIDE ECLIPSE

PHASE	LICK, JULY-AUG., 1951		McDONALD, AUG., 1953		BAGLOW, MAY, 1951	
	Yellow	Blue	Yellow	Blue	Yellow	Blue
Near 0 ^p 25	0 890	0 848	0 924	0 876	0 889	0 851
Near 46	.895	848			887	847
Near 75	911	862	0 901	0 857	897	852
Near 0 95	0 878	0 836			0 881	0 840

* Unit is the light of HD 164043 in each color

other hand, indications from the light-curves and predictions from theory agree that reflection and ellipticity effects in this system should be small, so that the uncertainties introduced into the results by a particular rectification procedure will be small. To carry out rectification of the Lick observations, I have adopted the constants in Table 4. The

TABLE 4
RECTIFICATION COEFFICIENTS

	Yellow	Blue		Yellow	Blue		Yellow	Blue
A_0	+0 890	+0 845	A_2	-0 004	-0 003	C_2	+0 003	+0 003
A_1	-0 0065	-0 004	C_0	+0 0085	+0 008	Nz	+0 029	+0 027

notation and precepts are those of Russell and Merrill (1952). The light outside eclipse is given by

$$I = A_0 + A_1 \cos \theta + A_2 \cos 2\theta ,$$

the reflected light by

$$C_0 - A_1 \cos \theta + C_2 \cos 2\theta .$$

The assumption was made that the cause of increased light near 0.75 phase does not affect the rest of the light-curve. The adopted reflection coefficients, A_1 , C_0 , and C_2 , were obtained from theory; A_0 and A_2 from the observations, the light at 0.75 phase being neglected.

The photometric eccentricity of the system, Nz , is obtained from A_0 , A_2 , C_0 , and C_2 . The dynamical eccentricities, z , of the individual components, predicted from the properties of the system derived later, are 0.004 for the brighter, smaller, and hotter star, and 0.020 for the fainter. The weighted ratio, N , of photometric to dynamical eccentricity is 3.3.

TABLE 5
LIGHT AT MINIMA

MINIMUM	OBSERVED (UNIT=COMPARISON STAR)		RECTIFIED (UNIT=LIGHT OUTSIDE ECLIPSE)	
	Yellow	Blue	Yellow	Blue
Primary	0 388	0 310	0 452	0 381
Secondary	0 810	0 786	0 908	0 930

It is to be emphasized that all the adopted quantities in Table 4 except Nz have uncertainties of a few units in the third decimal and that these uncertainties do not seriously affect the results of the analysis in the next sections; Nz is uncertain in the second decimal.

Depths of Minima

The observed and rectified brightnesses at mid-primary and -secondary eclipses, as obtained from the Lick observations, are given in Table 5 (see Figs. 5 and 6). Most of the change from observed to rectified light comes from the change in units of light, a minor amount (<0.02) from reflection and ellipticity effects. From the rectified light-

values in Table 5 one may evaluate (a) the colors of the individual components; (b) the surface-brightness ratio; and (c) the ratio of the radii.

a) The color of the light lost at any phase of either eclipse is simply the color of the eclipsed star. In Table 6 the colors of the components are obtained from the depths of the minima in the two colors. The corresponding spectral types are taken from Johnson and Morgan (1953). Corrections for differential limb darkening in the two colors and for reflected light, which are considered later, cannot change the colors of the stars by more than 0.02 mag.

b) The ratio of the surface brightnesses of the two stars is 6.0 in yellow light and 8.8 in blue light. The correction for reflected light is small. Adopting the temperature

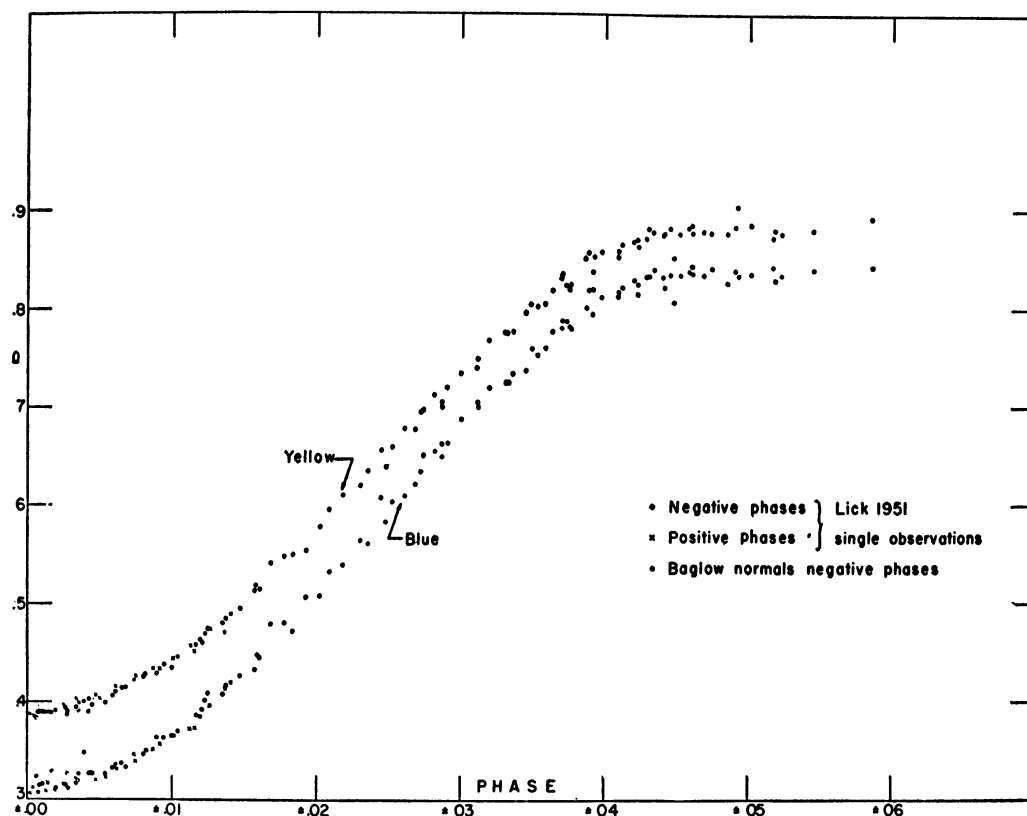


FIG. 5.—Primary minimum of Z Herculis

scale of Morgan and Keenan (1951) and Kuiper's (1938) bolometric corrections, we find the corresponding spectral-type difference to be F4–K3 V or F4–G5 III. Thus we see that the evidence from the colors of the stars and that from their surface brightnesses are in good agreement and do not contradict the evidence from the spectrograms. The most reliable indicator of spectral type in such a system, where the spectra always appear blended, is probably the color of the star. This statement is true, however, only if the observations are carried out in a *carefully standardized* color system, a practice not generally followed by observers of eclipsing variables. Three colors observed at the same time would be preferable to two, and, because of the calibration in terms of spectral type, the *U, B, V* system should be approximated. The colors of *both* components cannot, of course, be obtained so simply as in the case of Z Her unless both minima are sufficiently deep that the color of the eclipsed light can be determined with adequate precision.

c) If one assumes that the effective sizes of the components of an eclipsing system are the same in two colors and at both minima, the ratio of the radii may, in favorable cases, be obtained solely from the depths of the two minima in both colors. For the case of uniformly illuminated disks the relation is

$$k_U^2 = \frac{|\Delta l_0^{tr}|}{|\Delta l_0^{oc}|},$$

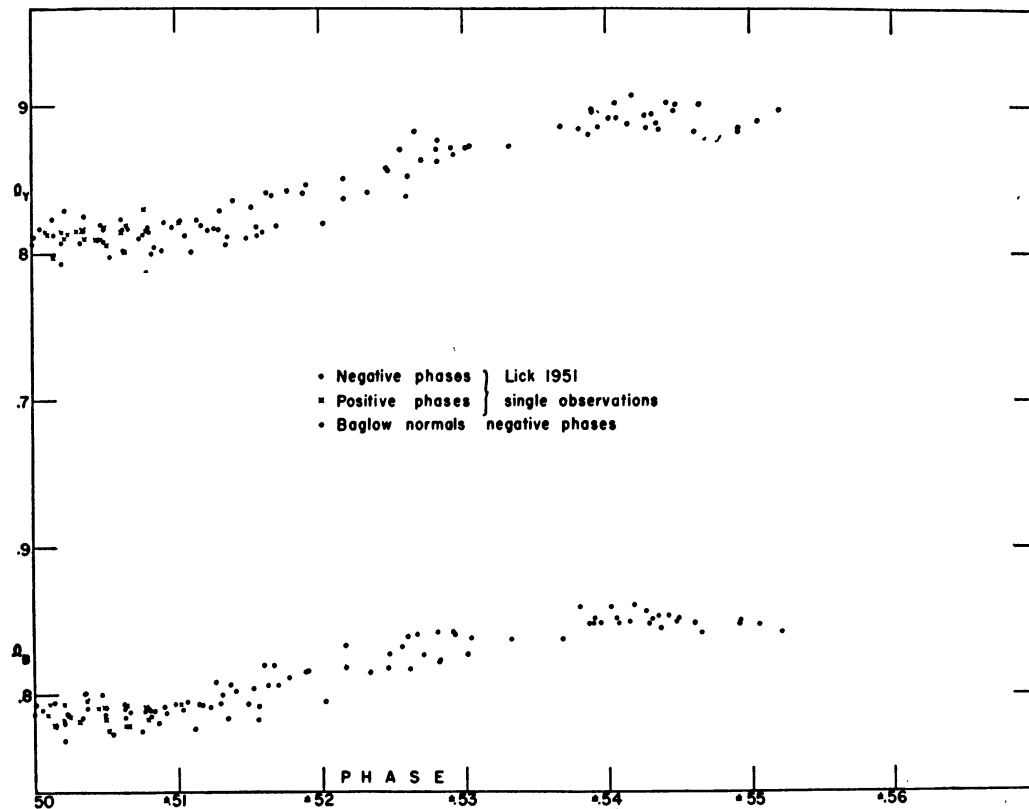


FIG. 6.—Secondary minimum of Z Herculis Above: yellow; below: blue

TABLE 6
COLORS OF Z HERCULIS ($B - V$ SYSTEM)

Color difference, Z Her (outside eclipse) — HD 164043	+0 056 ± 0 001 mag	
Color of HD 164043	+ 53 ± 01	
Color of Z Her outside eclipse	+0 59 ± 0 01	
	Hotter Star	Cooler Star
Color difference, eclipsed light — light outside eclipse	−0 13 mag.	+0 30 mag.
Color, $B - V$	+0 46	+0.89
Corresponding spectral type	F5–F6	{ K2 V G8–K0 IV G5 III

where k_U is the ratio of the radii ($k_U \leq 1$) in the uniform hypothesis, Δ signifies the difference between the two colors, I_0^{tr} is the light at mid-eclipse when the smaller star is in front (transit), and I_0^{oc} the light at mid-eclipse when the larger star is in front (occultation). The unit of light in each color must be the uneclipsed light of the system. From the larger color difference at primary minimum in the case of Z Her (see Table 5), we conclude immediately that the deeper eclipse must be an occultation, and we obtain $k_U^2 = 0.022/0.071$, or $k_U = 0.56$. I have found that this simple method of deciding in favorable cases whether the primary minimum is a transit or an occultation and of evaluating k_U was also proposed by Danjon (1928). It does not appear to have been used.

This method of determining k may be extended to darkened disks if one assumes the degree of limb darkening for each color and for each star to be known. From the depths of the two minima in a single color, one determines, with the aid of appropriate tables for the adopted degrees of limb darkening, a relation between k and p_0 , where p_0 is the geometrical depth of eclipse. A second relation is obtained for the other color, and the intersection of the two relations yields values of k and p_0 . The relevant tables in *Princeton Contribution* No. 23 (Merrill 1950) are tables of $x_g x_s k(q_0, a_0^{\text{oc}})$ and of $x_s p(k, a)$. The quantities x_g and x_s are the limb-darkening coefficients for the larger and the smaller star, respectively; a is the fractional loss of light; q_0 is a quantity obtained from the depths of the minima. In applying the method to Z Her, I have assumed the degrees of darkening and obtained the results shown in Table 7.

TABLE 7
SOLUTION FROM DEPTHS OF MINIMA

	Yellow	Blue		Yellow	Blue
x_g (adopted)	0 6	0 8	a_0^{oc}	0 80	0 81
x_s (adopted)	0 4	0 6	L_s (light of smaller star)	69	77
k	0 61		L_g (light of larger star)	0 31	0 23
p_0	-0 55				

There is some evidence that light on the disks of subgiant stars near spectral type K0, which the cooler component of Z Her turns out to be, is more strongly concentrated toward the center than the cosine law of limb darkening predicts (e.g., AR Lac, RT Lac). To test the effect of such a distribution of light, I have predicted the depths of secondary minima in Z Her, using the values of k , p_0 , and light of the components from Table 7, and the law of limb darkening given by the Gaposchkins (1945) for thick atmospheres. With the least extreme form of darkening given by them (their $n = 3$), the predicted depths do not differ by more than 0.001 mag. from those observed in either color, so that the results in Table 7 would not require modification on this account. It should not be concluded, however, that such a darkening law will not, in general, affect the depth of a transit eclipse—see, for example, the case of V356 Sgr (Popper 1955). The geometry of eclipse of Z Her is such that at mid-secondary eclipse the smaller star reaches from about the center of the larger star to somewhat beyond its limb, so that the average surface brightness of that part of the larger star covered at mid-eclipse approximates the average for the star as a whole. Such would not be the case for a central transit.

The method used in this section of obtaining k , p_0 , a_0 , and L from the depths of the minima in two colors will, in a favorable case, lead to a solution that is more determinate than that obtained in the usual manner from the shape and depths of minima in a single color. The observed quantities, ΔI_0^{tr} and ΔI_0^{oc} , being color differences, are determined with considerable precision in two-color photoelectric observations and are little affected by

ellipticity, reflection, intrinsic variability, etc. The method will not yield determinate results if the two stars are nearly the same color or if the eclipses are shallow, i.e., in the same cases in which the usual method is indeterminate.

From the results in Table 7 we see that the magnitude difference between the components of Z Her in blue light is 1.3 mag. Petrie (1950) found 0.4 mag. from photometry of the spectrum. Severe blending and the large differences in the equivalent widths of lines in the spectra of stars with such different spectral types make the spectrographic determination very uncertain.

Shape of Primary Minimum

Solution of the light-curve in the usual way from the shape of primary minimum (Fig. 5) and the depths of minima in a single color shows that k lies between 0.55 and 0.65, and a_0 between 0.85 and 0.77. This result is in good agreement with that from the depths of the minima in two colors. The solution from the depths alone appears the more determinate and will be adopted. Baglow (1952) concluded that k lies between 0.55 and 0.75. The yellow light-curves of both observers are difficult to fit near phase 0.01, the curvature being less than theory predicts.

The sizes of the stars and orbital inclination are well determined from the light-curve. Using $k = 0.60$ and the rectified primary minimum at depths of 0.6 and 0.9 of the maximum depth, we obtain $r_g = 0.180$, $r_s = 0.109$, $i = 85^\circ.1$, where r_g and r_s are, respectively, the radii of the larger and of the smaller star in units of the radius of the relative orbit. Using $k = 0.61$, $p_0 = -0.55$, and the rectified phase of the beginning of eclipse, we obtain $r_g = 0.189$, $r_s = 0.115$, $i = 82^\circ.6$. We adopt $r_g = 0.185$, $r_s = 0.113$, $i = 84^\circ$, and the photometric solution is complete except for corrections to the values of L in Table 7 for reflected light. These amount to less than 0.01 and are neglected. The close agreement of the results of this discussion with those of the completely independent investigation by Baglow should inspire confidence in their essential correctness.

DISCUSSION

The masses, luminosities, and radii of the components of Z Her can be computed from the data presented, except that, in addition, effective temperatures must be adopted to compute the luminosities. The effective temperatures should be consistent with the observed spectral types, particularly as derived from the colors, $B - V$. They must also satisfy the surface-brightness criterion,

$$\log \left(\frac{L_s}{L_g} \right) - 2 \log k = 4 \log \left(\frac{T_{es}}{T_{eg}} \right) + 0.4 (BC_s - BC_g),$$

where L_s and L_g are the brightnesses of the stars in yellow light (Table 7) and T_e and BC are the effective temperatures and bolometric corrections. The temperatures and bolometric corrections adopted are 6700° and -0.03 mag. for the hotter star, corresponding to spectral type F4 (Keenan and Morgan 1951), and 4600° and -0.35 mag. for the cooler star, corresponding to spectral type K0 IV. The color difference between the components is a bit less than that predicted by the surface-brightness ratio, but the discrepancy is not greater than the effects of uncertainties in the temperature scale and in the observations.

It is my opinion that the computed luminosities of most eclipsing binaries can be put on a sound basis only if effective temperatures are adopted primarily from properly standardized color observations. Estimated spectral types of blended spectra are not, in general, sufficiently trustworthy for this purpose. They should be used as checks on the colors, rather than vice versa. The fourth-power dependence of luminosity upon surface temperature should also be borne in mind.

Table 8 gives the principal results of the photometric analysis. Table 9 shows the properties of the two stars. With the exception of $B - V$, M_v , and spectral type, all quantities in Table 9 are in solar units. The uncertainties shown are meant to convey an idea as to the reliability of the results, which depend on a variety of data of widely differing precision. The luminosity classes given are those corresponding to the computed values of M_v . They have not been evaluated from the spectra. The F star is 0.7 mag. and the K star 2.2 mag. more luminous than a main-sequence star of the same color (Johnson and Morgan 1953).

Each component of Z Her has a mass and luminosity lying within the limits of the mass-luminosity plot for visual double stars as shown by Strand and Hall (1954), although the F star lies nearly 1 mag. above the mean relation for stars of its mass. It may be recalled that stars having probable errors in their luminosities up to ± 1.2 mag. are included in this plot.

TABLE 8
PHOTOMETRIC RESULTS

	Hotter Star	Cooler Star		Hotter Star	Cooler Star
L (yellow)	0.69 ± 0.04	0.31 ± 0.04	T_e	$6700^\circ \pm 300^\circ$	$4600^\circ \pm 250^\circ$
L (blue)	$.77 \pm .04$	$.23 \pm .04$	V	7.72 mag.	8.59 mag.
r	$.113 \pm .007$	$.185 \pm .015$			
$B - V$. . .	$+0.47 \pm 0.02$	$+0.91 \pm 0.03$	i	$84^\circ \pm 1^\circ$	

TABLE 9
PROPERTIES OF THE STARS

	Hotter Star	Cooler Star		Hotter Star	Cooler Star
$B - V$	$+0.47 \pm 0.02$	$+0.91 \pm 0.03$	M_v	$+2.9 \pm 0.2$	$+3.8 \pm 0.3$
Mass . . .	$1.22 \pm .06$	$1.10 \pm .04$	Spectral	F4 IV-V	K0 IV
Radius . .	1.6 ± 1	2.6 ± 2	type		
Luminosity	4.7 ± 0.8	2.8 ± 0.7	Density .	0.30	0.06

The essential result of this investigation is that improved spectrographic and photometric observations give a consistent picture of the components of the system, the values shown in Table 9 being among the better determinations in so far as eclipsing binaries are concerned. The importance of carrying out the photometric observations in a well-standardized color system is again emphasized. The principal remaining uncertainties in the properties of Z Her are due to intrinsic variations in the light of at least one component. These variations are worthy of further observation.

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