

REDISCUSSION OF ECLIPSING BINARIES. II. S ANTLIAE*

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ABSTRACT

On the basis of a new series of spectrograms of S Antliae it is concluded that the spectrum lines of the fainter component cannot be measured. Consequently, the masses and radii of the components cannot be determined. Correlation of the velocity-curve with a new light-curve shows that the hotter star is also the brighter and thus removes an ambiguity present in earlier discussions of the system.

INTRODUCTION

In 1949 Mr. A. R. Hogg, of the Commonwealth Observatory, Canberra, suggested that it would be desirable to obtain some new spectrographic observations of the 16-hour eclipsing binary, S Antliae,¹ to supplement those of Joy (1926). The observations were needed, in particular, to determine whether the brighter or fainter component is eclipsed at primary minimum. Such a long interval had elapsed between the dates of Joy's spectrograms, obtained in 1917–1921, and Hogg and Bowe's photoelectric light-curve (Hogg and Bowe 1950), obtained in 1949, that the correlation of spectrographic and photoelectric phases was uncertain by half a revolution. I did not obtain a series of spectrograms of S Antliae until 1954, five years after Hogg and Bowe's light-curve was observed. Upon examining the references to photometric observations of this star, it seemed that there was still some uncertainty in the phase correlations. Consequently, on a visit to the Lowell Observatory in the winter of 1955 a photoelectric light-curve of S Antliae was obtained. The present discussion is based on the more recent spectrographic and photometric observations.

SPECTROGRAPHIC DATA

Twenty-six prismatic spectrograms of S Antliae, having a dispersion of 34 Å/mm at H γ , were obtained principally with the Cassegrain spectrograph of the 100-inch telescope in 1954. The exposure times were 30 minutes (0.03 of the period). Because of improvements in spectrographs and photographic emulsions in the last thirty-five years, these spectrograms are stronger, wider, finer-grained, and extend to considerably shorter wave lengths than those obtained by Joy in 1917–1921 (Joy 1926).

The spectrograms are listed in Table 1. Phases are in fractions of the period after the middle of the deeper minimum. Spectrograms obtained near each of the nodes are reproduced in Figure 1. The lines of the brighter component have been placed together in the reproduction, the difference in radial velocity of about 160 km/sec between the two plates being shown by the relative positions of the two comparison spectra. Since the brighter component has negative velocities after the deeper minimum, it is seen immediately that the brighter star is the hotter, in agreement with Joy's conclusion.

The spectrograms have been examined and compared carefully to find the lines of the second component, use having been made of a spectrum comparator constructed particularly for this purpose. The only consistent evidence I am able to see that the fainter component is present is in the H lines; H δ and H γ show wings displaced in the opposite direction from the strong lines. In addition, it can be readily seen (Fig. 1) that the strong

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¹ HD 82610, var ; F0; α_{1900} 9^h27^m9; δ_{1900} — 28°11'.



FIG. 1.—Spectrograms of S Antliae. *Above*: plate E2778, 0.324 phase; *below*: plate E2802a, 0.834 phase. The spectrograms have been displaced relative to each other by the amount of their velocity difference, 160 km/sec, so that the stellar lines of the brighter component coincide.

components of $H\gamma$ do not show so large a radial-velocity variation as do the remaining lines. The same effect can be seen in $H\delta$. These effects of blending are confirmed by the radial-velocity measures of the H lines and, to a lesser extent, of other strong lines.

Thus it is evident that lines of the fainter component influence the appearance and positions of the stronger lines in the spectrum of S Antliae, so that the brightness ratio cannot be so large as the value 8:1 derived by Hogg and Bowe for the case of the brighter star being eclipsed at primary minimum. On the other hand, the lines of the fainter component do not appear as separate lines in the spectrum, so that the variation in the radial velocity of the fainter component cannot be determined with any degree of confidence.

TABLE 1
SPECTROGRAMS OF S ANTILIAE

Plate	U.T.	JD _{helio} 2430000+	Phase	No. of Lines	Velocity (km/sec)	O-C (km/sec)
1952						
γ 32446a	Apr. 5 211	4107 714	0 923	16	+ 53	+11
b	5.233	736	957	13	+ 15	- 8
1954						
E2776	Feb 11 285	4784 789	236	22	-101	- 8
2777	11 314	818	281	22	- 85	+ 7
2778	11 342	846	324	22	- 86	- 2
2779	11 369	873	366	21	- 65	+ 5
2780	11 394	898	404	22	- 53	0
2781	11 421	925	446	22	- 26	+ 6
2794	Apr 9 132	4841 635	915	21	+ 47	+ 1
2795a	9 159	662	956	19	+ 8	-16
b	9 188	691	001	22	+ 2	+ 4
2796a	9 215	718	043	20	- 30	- 4
b	9 241	744	083	19	- 60	-13
2797	9 269	772	126	21	- 77	-10
2802a	May 12 147	4874 648	834	22	+ 76	- 3
b	12 170	671	869	21	+ 70	+ 4
2861a	14 144	4876 645	914	21	+ 50	+ 4
b	14 167	668	949	22	+ 33	+ 5
2885	Dec. 12 437	5088 938	352	20	- 72	+ 3
2886a	12 465	966	395	21	- 52	+ 6
b	12 490	991	434	22	- 26	+12
c	12 516	5089 017	474	22	- 8	+ 8
d	12 541	042	513	20	- 3	- 9
1956						
2931a	Jan 2 417	5474 920	686	12	+ 83	0
b	2 458	961	750	20	+ 91	0
c	2 490	993	0 799	21	+ 85	- 2

Consequently, the radii and masses of the components of S Antliae must remain unknown. Examination of Joy's older plates, which, for reasons stated, are less suited to the purpose than the new ones, does not alter this conclusion. I wish to express appreciation to Dr. Joy for advice in this matter.

The spectral type of the brighter component appears a bit earlier than F0, in agreement with Joy's estimate of A8. The spectral type of the fainter component cannot be estimated from the spectrograms. From the apparent strength of its hydrogen lines, discussed in the second preceding paragraph, I should not expect it to be later than about F5. The color of the combined light, obtained from the photometric observations, corresponds to type F0. The surface-brightness ratio, 1.7, obtained by Hogg and Bowe, corresponds to a spectral-type difference A8-F3.

Radial-velocity measurements in the spectrum of a system such as S Antliae are beset with two difficulties. First, because of the width (axial rotation) and number of the lines, blending effects within the spectrum of a single component are serious, so that the normal wave length to be adopted for a given line is uncertain. Second, blending between lines of the two components will affect the positions of the lines. To analyze these problems, a separate velocity curve was drawn for each of the twenty-two lines chosen for measurement. Provisional values of K and γ were obtained by a graphical method for each line in the relation,

$$V = \gamma - K \sin \theta ,$$

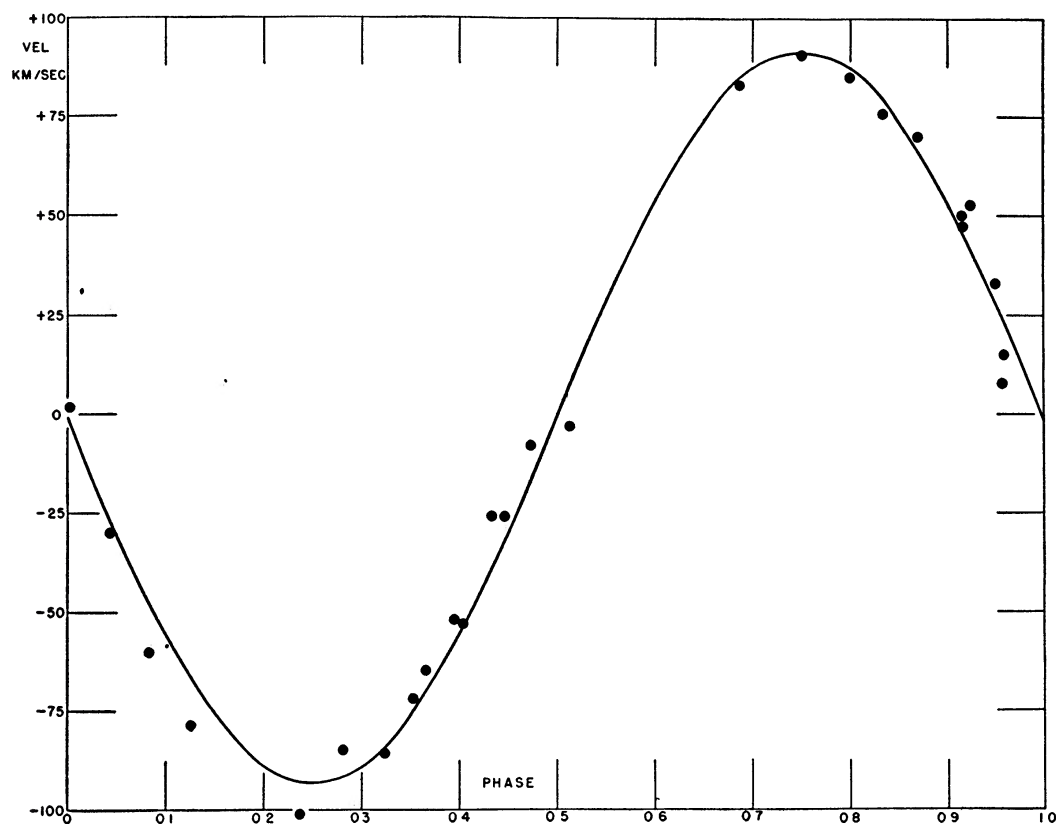


FIG. 2.—Radial velocities of S Antliae. The velocities are relative to an arbitrary zero. The curve is obtained from the adopted elements. Phases are in fractions of the period measured from the deeper eclipse.

where V is the measured velocity based upon an assumed wave length and θ is the phase angle measured from primary minimum. For seventeen of the twenty-two lines the values of K so obtained are scattered between 87 and 105 km/sec, the mean being 94.5. The values of K for the five strongest lines measured, K , $H\delta$, 4226, $H\gamma$, and 4481, are, on the other hand, 70, 66, 77, 48.5, and 80 km/sec, respectively. Consequently, these five lines were omitted from the radial-velocity reductions. The systematic difference, which is assumed to be due to blending with lines of the fainter component, is readily seen for $H\gamma$ in Figure 1. In order to obtain a consistent system of wave lengths for the remaining seventeen lines, the velocities measured for each line were corrected by subtracting the value of γ obtained for that line. The resulting mean velocities are listed in Table 1 and

plotted in Figure 2. The value of K obtained from these velocities and upon which the curve of Figure 2 and residuals of Table 1 are based, is

$$K = 92.3 \pm 1.5 \text{ km/sec.}$$

The difference between this value of K and the value 94.5 obtained from the individual lines is caused by different effective weighting of the lines in the two methods, as is the difference of γ from zero, its value being -1.2 ± 1.0 . The smaller value of K , 81 km/sec, obtained by Joy almost certainly results from his having included the stronger lines, which give systematically smaller velocity variations. A unique solution for the center

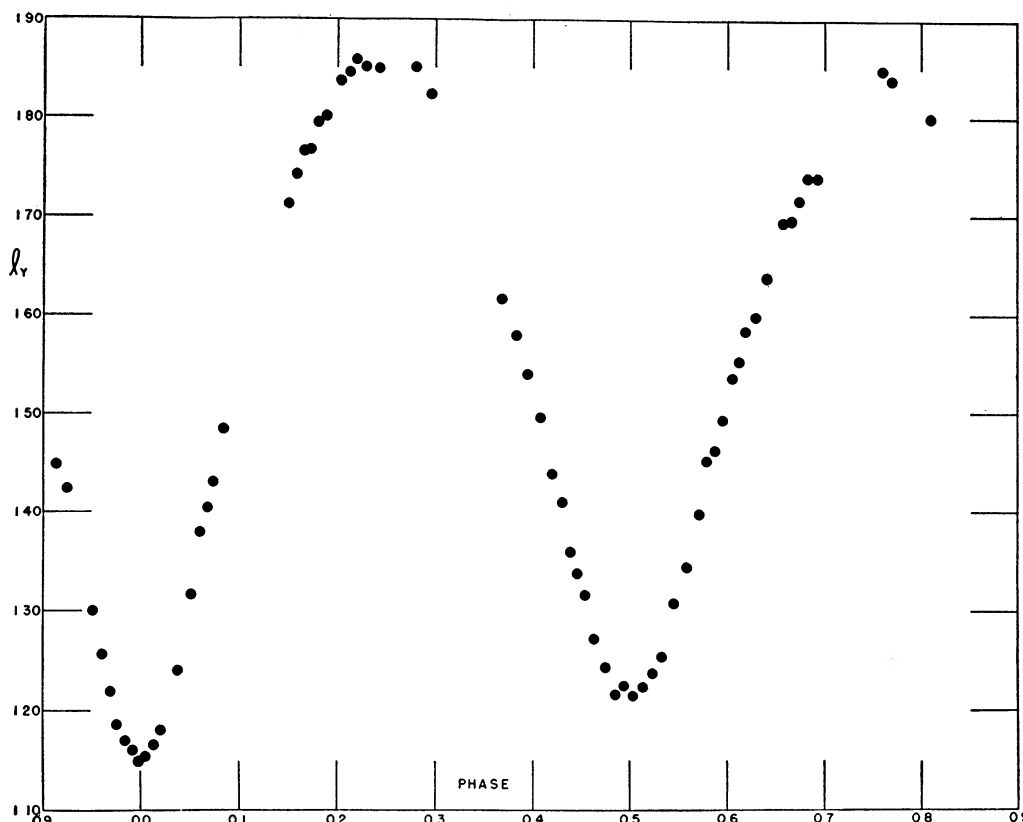


FIG. 3.—Light-curve of S Antliae in yellow light. Phases as in Fig. 2. The unit of the ordinates is the yellow light of the comparison star multiplied by 3.98. Each point is the mean of from three to five comparisons.

of mass velocity, γ , is not given by the procedure adopted. A value in the vicinity of $+15$ km/sec is indicated. From the value of K and the period we derive the following results:

$$a_1 \sin i = 1.2 \text{ solar radii,} \quad f(m) = 0.05 \text{ solar masses.}$$

PHOTOMETRIC DATA

S Antliae was observed on 10 nights between January 24 and February 8, 1955, with a photoelectric photometer attached to the 21-inch Cassegrain reflector at the Lowell Observatory. This instrument employs a 1P21 photomultiplier, A.C. linear amplifier, and Brown recorder. The color filters are those of the U , B , V system (Johnson and

Morgan 1953). Most of the observations were through the yellow filter. The comparison star employed was HD 82575.² The comparison star used by Hogg and Bowe (1950), ζ^2 Antliae, differs too much in zenith distance from S Antliae, as seen from Flagstaff, to be useful. The observing was carried out within 2 hours of the meridian because of the relatively large zenith distance of the stars. The correction for differential extinction between the two stars at an hour angle of 2 hours is 0.007 mag. in yellow light. Figure 3 shows the yellow light-curve.

Times of Minima and Period

The observed time of primary minimum is $\text{JD}_{\text{helioe}} 2435139.929 \pm 0.001$ (est.). Combining this result with Hogg and Bowe's observed date of primary minimum leads to a period of 0.648345 day, while combining Hogg and Bowe's and my minima with the older set of observations compiled by Luizet (1904) gives a period of 0.648342. The minima of the older set appear to require a period of 0.648340, so there is evidence of a slight lengthening of the period. The period 0.648345 has been used in conjunction with my observed time of primary minimum to compute the phases used in this paper.

The epoch of zero phase published by Luizet and used by Joy (1926) in his analysis of the system refers to the *deeper* eclipse. This conclusion is contrary to that reached by Hogg and Bowe. As confirmed by a letter from Mr. Hogg, the paper by Hogg and Bowe unfortunately contains an error in the date of primary minimum. The epoch JD 2432920.7715 is incorrect, so that conclusions drawn with its use are invalid. The time of primary minimum observed by Hogg and Bowe is JD 2432962.139. It was this mistake that caused the difficulty in phase correlation mentioned in the introduction of this paper.

Discussion of the Light-Curve

The observations in yellow light outside eclipse (0.15 or more of the period from both minima) are fitted by the relation

$$l_x = l_0 (1 + 0.029 \cos \theta - 0.147 \cos 2\theta),$$

θ being the phase measured from primary minimum. This relation is in good agreement with that of Hogg and Bowe for unfiltered light:

$$l - l_0 (1 + 0.024 \cos \theta - 0.145 \cos 2\theta).$$

In particular, the sign of the coefficient of $\cos \theta$ is confirmed to be the opposite of that given by the usual reflection effect. (Their published value of the coefficient of $\cos 2\theta$, -0.016 , is a misprint.)

Rectification of the light-curve in the usual way leads to fractional losses of light of 0.194 at primary minimum and 0.094 at secondary. These values are to be compared with 0.194 and 0.112, obtained by Hogg and Bowe. The spectrographic results show unambiguously that the brighter star is eclipsed at the deeper minimum and hence is the hotter. This result is in agreement with that adopted by Joy but is contrary to that favored by Hogg and Bowe.

I have not considered it worthwhile to carry the analysis of the light-curve of S Antliae any further. Rectification procedures are, for a system with components as greatly distorted as those of S Antliae, at best uncertain. When, as in this case, the stars are nearly in contact, the mass ratio is unknown, and the eclipses are partial, it is doubtful that meaningful results can be obtained. In the solution by Hogg and Bowe, as well as that by Joy, it was assumed that the two stars are ellipsoids of the same shape, the geometrical ellipticities being the same as the photometric ellipticities. These assumptions are

² HD 82575; 8.1 F0; α_{1900} 9^h27^m7; δ_{1900} $-28^\circ 36'$.

poorly based, as are conclusions determined from them. The result of Hogg and Bowe, for example, that, if the brighter star is eclipsed at the deeper minimum, the brightness ratio of the components is 8/1, is not compatible with the spectrographic observations. Since, in any case, the masses and radii of the components of S Antliae cannot be obtained because the radial velocities of the fainter component are not observable, inability to solve the light-curve does not deprive us of information concerning the basic properties of the stars of this system.

The principal purpose of the 1955 photoelectric observations of S Antliae was to determine the epoch of the deeper eclipse. Because of the limited observing time available and the large zenith distance of the star, it was considered advisable to concentrate on the light-curve in a single color. As a result, color variations of S Antliae are not very well determined. The $B - V$ color shows no systematic variations with phase larger than 0.01 mag. The color of the system is

$$B - V = +0.33 \pm 0.01, \quad U - B = -0.01 \pm 0.01.$$

These colors are those of a main-sequenced star of spectral type F0 (Johnson and Morgan 1953). At maximum light the magnitude of the system is $V = 6.28$.

DISCUSSION

The most important conclusion to be drawn from this investigation is that S Antliae should be removed from lists of stars of which the masses and radii of the components are presumed to be determined observationally.

It has been a privilege to use the facilities of the Mount Wilson and Lowell Observatories, as well as to discuss the problem of S Antliae with Dr. Joy. I am indebted to Mr. Hogg for emphasizing the desirability of obtaining a new series of spectrograms.

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