

# PROVISIONAL ELEMENTS AND DIMENSIONS OF S ANTLIAE CONSIDERED AS AN ECLIPSING BINARY<sup>1</sup>

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## ABSTRACT

*Spectrographic observations.*—The spectrum is similar to that of W Ursae Majoris in that it shows wide double lines, but the type for both components is estimated to be A8. Luizet's double period, 0.64833872 day, fits the observations. *Nineteen spectrograms* (Table I), obtained with a single prism, serve to determine the *elements* of the orbit:  $e=0.0$  (assumed);  $\gamma=-5.0$  km/sec.;  $K_1=81$  km/sec.;  $K_2=148$  km/sec.

*Photometric orbit.*—The Harvard photometric observations have been used to determine a light-curve and an orbit, the star being considered as an eclipsing variable. The results indicate that the *components* are *very close* together and greatly *elongated*. The *eclipse* is *partial*.  $a_0=0.36$ ;  $k=0.77$ ;  $i=62^\circ 10'$ . Judged from their spectra, the light of the brighter star is twice that of the fainter.

*Absolute dimensions.*—The spectrographic and photometric observations are combined to give the dimensions of the stars and the system: radius of relative orbit = 2,300,000 km; semi-major axis of large star = 1,160,000 km; semi-major axis of small star = 896,000 km; distance of surfaces = 251,000 km;  $m_1=0.75 \odot$ ;  $m_2=0.42 \odot$ ;  $\rho_1=0.31 \odot$ ;  $\rho_2=0.38 \odot$ .

The light-changes of the southern variable, S Antliae ( $9^h 29^m 7$ ,  $-28^\circ 11'$ , 1900), were first detected by H. M. Paul<sup>2</sup> at Washington in 1888. Its period was then the shortest known. The early observers, Sawyer, Yendell, and Chandler, placed the variable in the Algol class on account of the sharp minimum and flat maximum; but, in 1896, E. C. Pickering<sup>3</sup> made a series of observations with the meridian photometer and concluded that the star was not an eclipsing variable, because the minimum occupied such a large portion of the period and because the light-change at maximum was continuous. O. C. Wendell<sup>4</sup> observed portions of four minima in 1898 with the polarizing photometer, finding odd and even minima of nearly equal depth. Luizet,<sup>5</sup> in 1904, compared his observations with earlier measures and gave corrected elements of such accuracy as to hold very closely up to the time of the present observations. Since

<sup>1</sup> *Contributions from the Mount Wilson Observatory*, No. 322.

<sup>2</sup> *Astronomical Journal*, 9, 180, 1890.

<sup>3</sup> *Astronomische Nachrichten*, 142, 12, 1896.

<sup>4</sup> *Annals of the Harvard College Observatory*, 69, 44, 1909.

<sup>5</sup> *Astronomische Nachrichten*, 165, 291, 1904.

the light-curve does not differ widely from that which would be given by a single rotating ellipsoid, Shapley<sup>1</sup> included the star in his list of such objects. Plummer<sup>2</sup> has noted certain irregularities in the light-curve which led him to associate it with the short-period cluster-type of variables.

TABLE I  
SPECTROGRAPHIC OBSERVATIONS

| PLATE               | DATE         | G.M.T.                         | PHASE  | VELOCITY |         | O-C     |         | Wt.   |       |
|---------------------|--------------|--------------------------------|--------|----------|---------|---------|---------|-------|-------|
|                     |              |                                |        | Prim.    | Sec.    | Prim.   | Sec.    | Prim. | Sec.  |
|                     |              |                                |        | km/sec.  | km/sec. | km/sec. | km/sec. |       |       |
| $\gamma$ 6397.....  | 1917 Nov. 27 | 0 <sup>h</sup> 47 <sup>m</sup> | 0.3279 | +19      | .....   | +21     | .....   | 1.0   | ..... |
| 6435.....           | Dec. 4       | 0 52                           | .1996  | -67      | +137    | +14     | +4      | 0.5   | 1.0   |
| 6505.....           | 9            | 22 36                          | .1717  | -80      | +149    | +1      | +1      | 1.0   | 0.5   |
| 6727.....           | 1918 Mar. 2  | 19 12                          | .1411  | -87      | +149    | -3      | +9      | 0.5   | 0.5   |
| 6810.....           | 30           | 17 20                          | .1848  | -82      | +122    | +2      | -17     | 0.5   | 0.5   |
| 7798.....           | 1919 Jan. 18 | 21 25                          | .0091  | -26      | .....   | -14     | .....   | 1.0   | ..... |
| 7970.....           | Mar. 17      | 18 12                          | .1729  | -84      | +146    | +2      | +4      | 1.0   | 1.0   |
| 8023.....           | Apr. 10      | 15 35                          | .0761  | -68      | +55     | -9      | -39     | 1.0   | 1.0   |
| 8024.....           | 10           | 16 35                          | .1171  | -76      | +135    | +2      | -7      | 1.0   | 1.0   |
| 8037.....           | 11           | 16 14                          | .4542  | +55      | -137    | -17     | +9      | 1.0   | 0.5   |
| C 798.....          | 1920 Nov. 29 | 1 10                           | .0581  | -56      | +69     | -6      | -4      | 1.0   | 1.0   |
| C 939.....          | 1921 Mar. 16 | 17 37                          | .0776  | -51      | +91     | +9      | -5      | 1.0   | 1.0   |
| $\gamma$ 10082..... | Apr. 16      | 15 50                          | .5731  | +54      | -146    | +5      | -42     | 1.0   | 0.5   |
| 10084.....          | 16           | 17 05                          | .6252  | +14      | .....   | +3      | .....   | 1.0   | ..... |
| 10089.....          | 17           | 15 21                          | .2564  | -77      | +57     | -23     | -27     | 0.5   | 0.5   |
| 10092.....          | 17           | 17 07                          | .3300  | -4       | .....   | -3      | .....   | 1.0   | ..... |
| 10109.....          | 21           | 15 40                          | .3795  | +35      | -102    | -2      | -21     | 1.0   | 0.5   |
| 10123.....          | 25           | 16 39                          | .5304  | +83      | -172    | +15     | -33     | 0.5   | 0.5   |
| C 1012.....         | May 13       | 16 02                          | 0.3512 | +22      | .....   | +6      | .....   | 0.5   | ..... |

#### SPECTROGRAPHIC OBSERVATIONS

The Harvard estimate of the spectral type is Fo. The first photographs of the spectrum obtained at this observatory were taken for the purpose of determining the absolute magnitude and parallax. It was immediately seen<sup>3</sup> that the spectrum is very different from that of Cepheid or cluster-type variables, the lines being wide and hazy, because of a large rotational effect like that found in W Ursae Majoris. In some cases the lines appeared to be double. On account of the character of the spectrum, the plates are extremely difficult to

<sup>1</sup> *Astronomische Nachrichten*, 194, 353, 1913.

<sup>2</sup> *Monthly Notices of the Royal Astronomical Society*, 73, 659, 1913.

<sup>3</sup> Adams and Joy, *Publications of the Astronomical Society of the Pacific*, 31, 41, 1919.

measure and the results are accordingly uncertain, especially in the case of the secondary spectrum. As more observations were obtained, it became evident that the period of light-variation could be used to plot the velocity changes only if the double period of sixteen

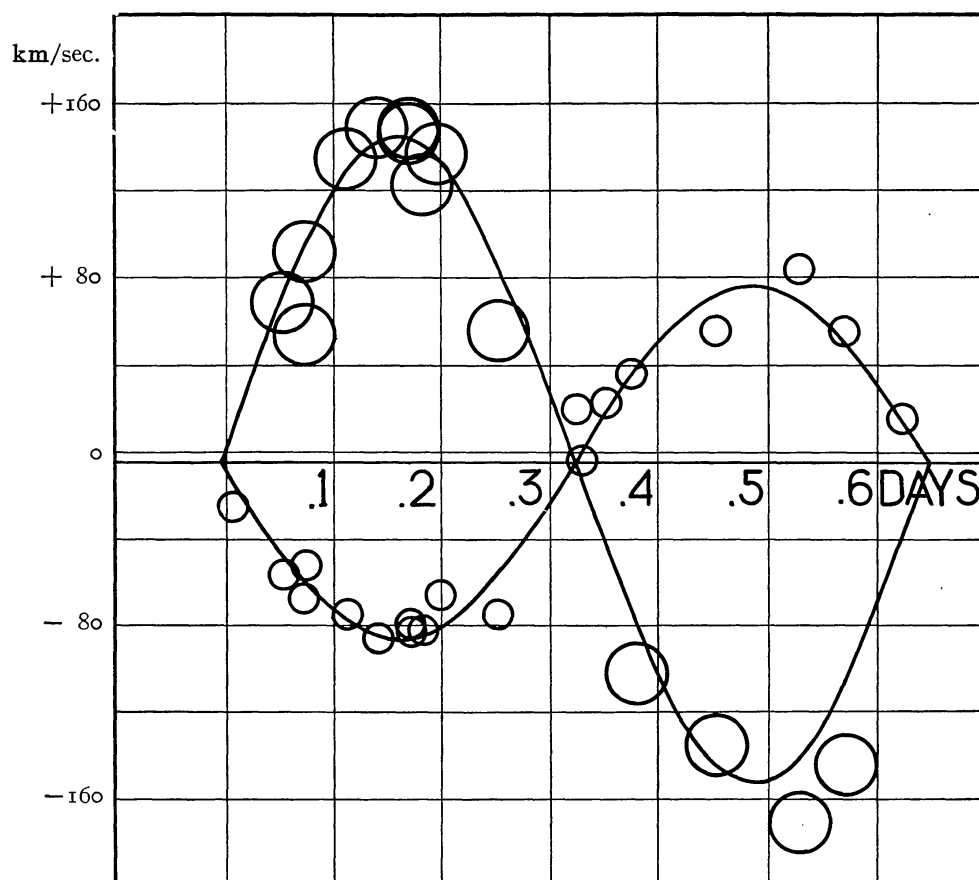


FIG. 1.—Velocity-curves of the components of *S* Antliae

hours were adopted. The predicted maximum of light occurs at the time of maximum separation of the two components of the spectrum, and minimum of light when the spectrum is single. It is therefore concluded that the star must be an eclipsing binary having ellipsoidal components of nearly the same surface brightness which partially eclipse each other. The spectral type is estimated as A8 for each star, but there is much uncertainty in the case of the fainter spectrum. On many of the plates, the weaker lines of both compo-

nents are lacking, and the stronger lines very poorly defined. The lines of the secondary are always measured with difficulty. The low altitude of the star caused some of the spectrograms to be weak in the violet region.

Nineteen plates were obtained as given in Table I. All were measured at least once by the writer, and the weight for most of them is increased by the measures of Mr. Adams and Miss Burwell.

Since neither the photometric observations nor the velocity-curve show any indication of eccentricity, the orbit is assumed to be circular. Separate solutions were made to determine the correction to the remaining elements of the primary and secondary. The velocity of the system,  $\gamma$ , was not included in the secondary solution, since it was considered to be more accurately defined by the solution for the primary. When the period is doubled, the photometric elements of Luizet,

$$\text{Min.} = \text{J.D. } 2410741.5248 + 0.64833872 \text{ day (G.M.T.)}$$

satisfy the observations very exactly. Since more than eighteen thousand complete revolutions have taken place since the initial epoch, it is evident that the period cannot have changed by as much as one-tenth of a second in thirty years.

The corrected elements of the spectrographic orbit as determined by the observations are:

$$\begin{array}{ll} e = 0.0 \text{ (assumed)} & a_1 \sin i = 722,000 \text{ km} \\ \gamma = -5.0 \pm 1.8 \text{ km/sec.} & a_2 \sin i = 1,320,000 \text{ km} \\ K_1 = 81 \pm 2.5 \text{ km/sec.} & m_1 \sin^3 i = 0.52 \\ K_2 = 148 \pm 11.6 \text{ km/sec.} & m_2 \sin^3 i = 0.29 \end{array}$$

The residuals in the seventh and eighth columns of Table I are computed from these elements.

#### PHOTOMETRIC ORBIT

The outcome of the spectroscopic observations makes it worth while to re-examine the available photometric data, with a view to the determination of other facts concerning this well-known variable. It is of especial interest to see whether it is possible to account for

the observed light-changes by assuming that the two bodies are ellipsoidal stars partially eclipsing each other.

The observations with the meridian photometer by Pickering<sup>1</sup> in 1896 and those of Wendell<sup>2</sup> in 1898 with the sliding-prism polarizing photometer have been used, the latter being adjusted to the meridian observations by applying a correction of +0.16 mag. The measures were grouped according to time in twenty-three normal places as given in Table II. The phases were determined from Luizet's elements.

TABLE II  
HARVARD PHOTOMETRIC OBSERVATIONS

| Mean Mag. | Mean Phase | No. | Mean Mag. | Mean Phase | No. | Mean Mag. | Mean Phase | No. |
|-----------|------------|-----|-----------|------------|-----|-----------|------------|-----|
| 6.84..... | 0.006      | 6   | 6.45..... | 0.227      | 12  | 6.38..... | 0.435      | 4   |
| 6.75..... | .016       | 7   | 6.53..... | .251       | 7   | 6.46..... | .460       | 18  |
| 6.67..... | .028       | 7   | 6.61..... | .272       | 7   | 6.38..... | .502       | 17  |
| 6.56..... | .051       | 9   | 6.76..... | .318       | 4   | 6.41..... | .545       | 3   |
| 6.52..... | .065       | 5   | 6.79..... | .325       | 5   | 6.55..... | .576       | 19  |
| 6.38..... | .098       | 6   | 6.71..... | .349       | 17  | 6.67..... | .610       | 15  |
| 6.31..... | .146       | 7   | 6.65..... | .371       | 23  | 6.79..... | 0.636      | 16  |
| 6.39..... | 0.204      | 28  | 6.53..... | 0.398      | 8   |           |            |     |

The observations show large errors, probably because of the southern declination of the star. Too much confidence should not be placed upon the arbitrary light-curve, which has been drawn as shown in Figure 2. It is evident, however, that the minima are not exactly equal in depth, and that after allowing for a considerable ellipticity, there remains a small percentage loss of light which may be caused by eclipse.

Using Russell's<sup>3</sup> method and notation, we find by plotting  $\cos^2\theta$  against  $1-L^2$ , the magnitudes being reduced to intensities, that  $z=0.340$ . The rectified curve then shows that the loss of light because of eclipse is 0.145 at primary and 0.120 at secondary minimum. The loss because of the ellipticity of the stars is 0.188.

By setting different values for  $a_0$  and  $k$  in the equation

$$a_0 = 1 - \lambda_1 + \frac{1 - \lambda_2}{k^2},$$

<sup>1</sup> *Harvard Annals*, 46, 124, 1903.

<sup>2</sup> *Ibid.*, 69, 44, 1909.

<sup>3</sup> *Astrophysical Journal*, 35, 315; 36, 54, 1912.

it is seen that the orbit would be largely indeterminate were it not for the assistance of the spectroscopic data at this point. The spectrograms indicate that one star is brighter than the other in the ratio of approximately 2:1. After calculating the ratio of surface brightnesses by comparing the minima and the total light of the two stars, the ratio of the radii,  $k$ , is found to be 0.775. Had the ratio 3:2 been used instead of 2:1, the resulting dimensions of the stars would have been changed by less than 10 per cent. A light-curve was computed with  $k=0.775$  and  $a_0=0.36$  which fits the rectified light-curve at minimum within the uncertainties of the observations.

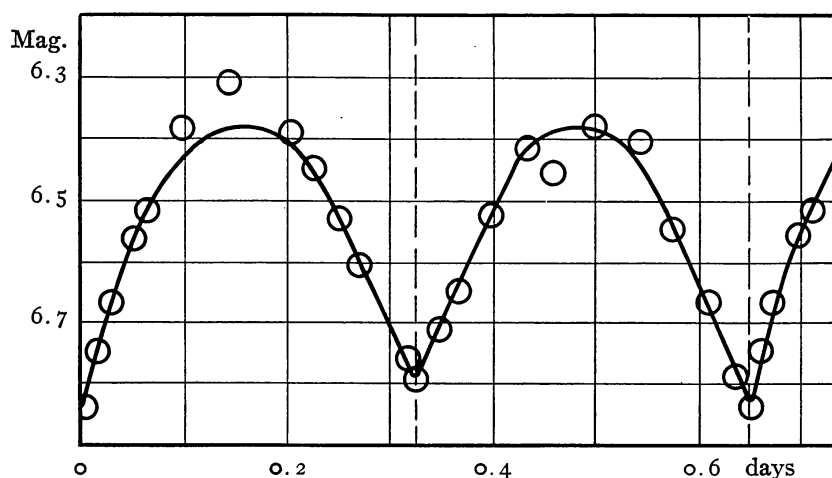


FIG. 2.—Light-curve of S Antliae

If we take 0.09 day before minimum as the beginning of eclipse, the corresponding value of the longitude,  $\theta'$ , may be computed, and the inclination,  $i=62^\circ 10'$ , may be found from the equations

$$a_1^2(1-z)[1+kp(k, a_0)]^2 = \cos^2 i$$

$$a_1^2(1-z \cos^2 \theta')(1+k)^2 = \cos^2 i \cos^2 \theta' + \sin^2 \theta'.$$

The dimensions of the stars in terms of the radius of the relative orbit are:

|                                           |                 |       |
|-------------------------------------------|-----------------|-------|
| Semi-major axis of larger star. . . . .   | $a_1$ . . . . . | 0.502 |
| Semi-minor axis of larger star . . . . .  | $b_1$ . . . . . | .377  |
| Semi-major axis of smaller star . . . . . | $a_2$ . . . . . | .389  |
| Semi-minor axis of smaller star . . . . . | $b_2$ . . . . . | 0.292 |

The value of the inclination of the orbit having been determined from the photometric observations, it is possible to give absolute values for the dimensions of the system by combining the photometric and spectroscopic elements. We thus find:

|                                      |                   |                |
|--------------------------------------|-------------------|----------------|
| Period.....                          | $P$ .....         | 0.64833872 day |
| Orbital eccentricity.....            | $e$ .....         | 0.00 (assumed) |
| Light of bright star.....            | $L_1$ .....       | 0.67           |
| Ratio of surface brightness.....     | $J_b/J_f$ .....   | 1.2            |
| Spectral type, both stars.....       |                   | A8             |
| Ratio of radii of stars.....         | $k$ .....         | 0.775          |
| Percentage of eclipse.....           | $a_0$ .....       | 0.36           |
| Duration of eclipse.....             |                   | 0.180 day      |
| Magnitude at maximum.....            |                   | 6.39           |
| Magnitude at primary minimum.....    |                   | 6.83           |
| Magnitude at secondary minimum.....  |                   | 6.79           |
| Inclination of orbit.....            | $i$ .....         | $62^\circ 10'$ |
| Radius of relative orbit.....        | $a_1 + a_2$ ..... | 2,300,000 km   |
| Radius of primary orbit.....         | $a_1$ .....       | 817,000        |
| Radius of secondary orbit.....       | $a_2$ .....       | 1,490,000      |
| Semi-major axis, large star.....     |                   | 1,160,000      |
| Semi-minor axis, large star.....     |                   | 870,000        |
| Semi-major axis, small star.....     |                   | 896,000        |
| Semi-minor axis, small star.....     |                   | 674,000        |
| Distance of surfaces.....            |                   | 251,000        |
| Mass, primary large star.....        | $m_1$ .....       | 0.75 $\odot$   |
| Mass, secondary small star.....      | $m_2$ .....       | 0.42           |
| Density, large star.....             | $\rho_1$ .....    | 0.31           |
| Density, small star.....             | $\rho_2$ .....    | 0.38           |
| Absolute magnitude, bright star..... | $M$ .....         | 2.9            |
| Parallax.....                        |                   | 0".017         |

The difference in velocity at the two limbs of the larger star due to rotation is 225 km/sec., which easily accounts for the character of the spectral lines. For determining the absolute magnitude the brighter star was assumed to have a surface brightness 1.1 mag. brighter than that of the sun. No darkened solution was attempted on account of the inaccuracy of the light-curve, but it seems probable from inspection that the observations would have been somewhat better represented by the assumption of darkening at the limb.

It therefore appears that the variable S Antliae should be classed among the eclipsing binaries. The light-changes can be accounted for by ellipticity of the stars and by the partial eclipse of the larger, brighter, and more massive star at primary minimum. The star will repay further accurate photometric observation, for the present results must be affected by a considerable degree of uncertainty.

Of those variable stars which have been suggested as single rotating ellipsoids, not one has been found to meet the necessary spectrographic requirements.

MOUNT WILSON OBSERVATORY  
August 1926