

THE LUMINOSITY OF THE CEPHEID Y OPHIUCHI

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INTRODUCTION

Y Ophiuchi is a 17-day cepheid which is anomalous¹ in that its ranges in light, color, and radial velocity are less than half of those for other classical cepheids of the same period. The question arises whether its radius and luminosity are also different from those for normal cepheids. To investigate this problem we have applied Wesselink's method² in which it is assumed that for phases of equal color the difference in light is due to a difference in surface area. The light-measures then give relative radii, and an integration of the velocity-curve gives the difference in radius in kilometers; a comparison yields the radius and luminosity of the star.

SPECTROGRAPHIC RESULTS

Radial velocity-curves for Y Oph have been published by others^{3,4} but they were not obtained concurrently with photometric observations. Therefore a new velocity-curve was obtained with the Mills spectrograph (dispersion 11 Å/mm. at λ 4500) of the Lick 36-inch refractor during the summer of 1953 when Eggen was observing the star photoelectrically. The times of observations, phases, and observed radial velocities are given in Table I. The phases were computed from the ephemeris

$$\text{light-maximum} = \text{JD } 240\,8694.86 + 17.11884 \text{ E.} \quad (1)$$

The measured velocities were corrected for the earth's diurnal and annual motion and for telescope flexure. The velocity-curve is shown in Figure 1.

All spectra of good quality were classified by comparison with spectra of revised⁵ Morgan-Keenan-Kellman standards of luminosity class Ib. The classification was based on the metallic lines only, since no hydrogen lines are in the range of good focus

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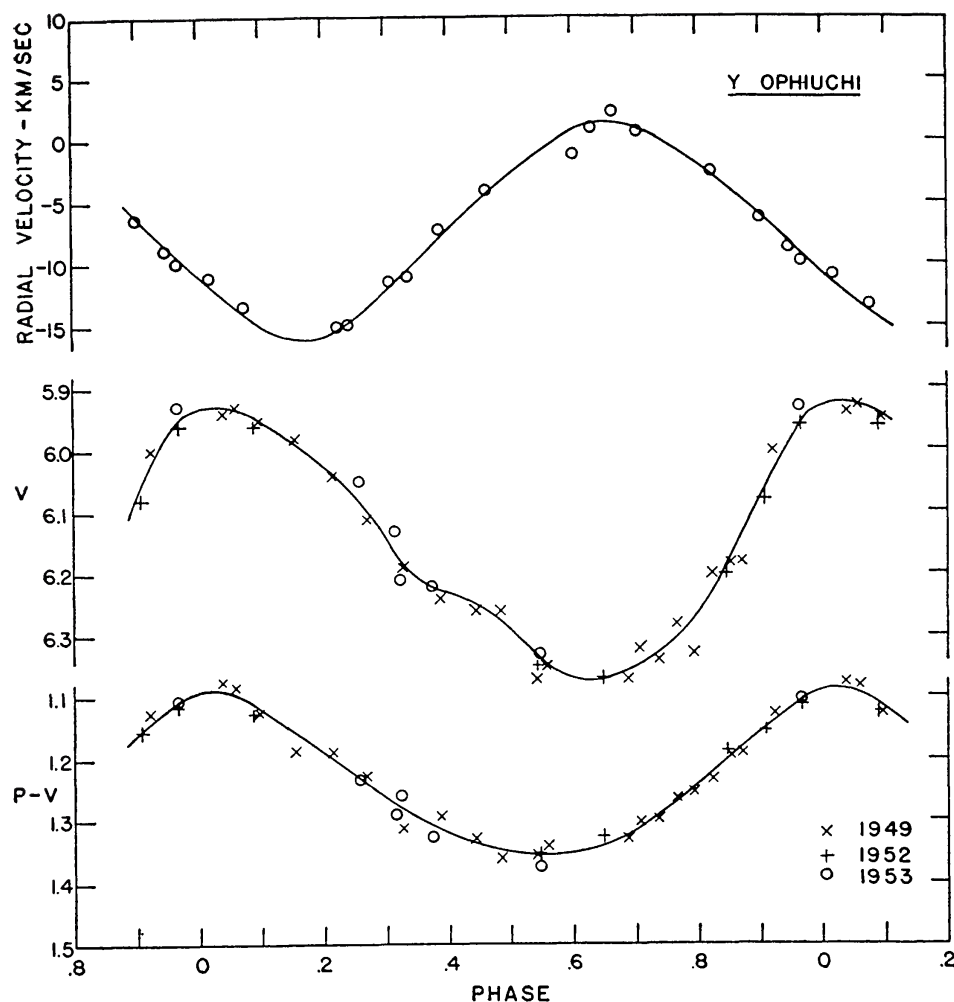


FIG. 1.—*Top*: radial velocities. *Center and bottom*: photoelectric visual magnitudes and colors, respectively, by Eggen.

and exposure on the Mills plates. However, the hydrogen line intensities seem to be consistent with the classifications. The results are given in Table I.

PHOTOMETRIC RESULTS

Eggen has published¹ photoelectric observations of Y Oph taken with the Lick 12-inch refractor in 1948 and 1949. In 1952 and 1953 he obtained additional observations. The first set of observations has since been re-reduced from the original tracings, and all measures made before 1949 June 1 (with different equipment) were discarded. All measures were converted⁶ to

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TABLE I
SPECTROGRAPHIC OBSERVATIONS

Plate LS—	JD 243 4000+	Cycle and Phase Period 1500+	Radial Velocity	Spectral Type
36435	441.032	3.967	— 9.9 km/sec	F9 Ib
469	453.003	4.666	+ 2.1	G0 Ib
479	458.999	5.017	—11.0	F8 Ib
484	459.983	5.074	—13.3	F8 Ib
496	463.990	5.308	—11.4	G0 Ib
536	474.966	5.949	— 8.9	F9 Ib
543	479.951	6.241	—14.9	F9 Ib
570	489.941	6.824	— 2.6	F9 Ib
603	500.962	7.462	— 4.1	G3 Ib
642	513.901	8.224	—15.0	...
649	515.820	8.336	—11.0	...
706	533.846	9.389	— 7.2	...
851	571.749	11.603	— 1.2	G2 Ib
865	576.843	11.901	— 6.4	F9 Ib
978	607.709	13.704	+ 0.6	...
37111	640.702	15.631	+ 1.0	...

the **P,V** system and are given in Table II. Phases were computed with equation (1). I am indebted to Dr. Eggen for furnishing these observations.

The visual magnitudes and colors are plotted in Figure 1. Observations in different years, indicated by different symbols, are seen to fit the same ephemeris. A comparison with the velocity-curve, which was obtained concurrently with the 1953 photoelectric observations, shows that minimum velocity occurs 0.16P after maximum light, and that maximum velocity occurs 0.03P after minimum light. This phase shift between light- and velocity-curves had been suspected by Sanford.⁴

A comparison of the colors in Figure 1 with the spectral types in Table I shows that the star is highly reddened. A color excess of 0.54 ± 0.03 (p.e.) was derived by comparing the observed colors with those corresponding to the observed spectral types, on the basis of Eggen's correlation¹ between color and spectral type for the least reddened stars of luminosity class Ib. The two color-curves agree with each other in shape and phase within the accuracy of the spectral classification.

TABLE II
EGGEN'S PHOTOELECTRIC MEASURES

JD 243 0000+	Cycle and Phase Period 1400+	V	P-V
3069.889	23.872	6.18	1.189
3083.854	24.687	6.37	1.329
3087.854	24.921	6.00	1.127
3089.837	25.037	5.94	1.076
3090.837	25.095	5.95	1.125
3091.809	25.152	5.98	1.185
3092.816	25.211	6.04	1.186
3093.788	25.268	6.11	1.228
3094.785	25.326	6.19	1.311
3095.792	25.385	6.24	1.294
3096.781	25.442	6.26	1.330
3098.771	25.559	6.35	1.340
3101.826	25.737	6.34	1.299
3102.792	25.794	6.33	1.253
3103.799	25.852	6.18	1.192
3131.722	27.484	6.26	1.359
3132.701	27.541	6.37	1.352
3152.674	28.707	6.32	1.301
3153.684	28.766	6.28	1.261
3154.677	28.824	6.20	1.232
3158.663	29.057	5.93	1.084
4134.986	86.089	5.96	1.125
4147.965	86.848	6.20	1.186
4159.906	87.545	6.35	1.355
4195.875	89.646	6.37	1.326
4251.722	92.909	6.08	1.155
4252.729	92.967	5.96	1.112
4549.840	110.323	6.21	1.259
4560.833	110.965	5.93	1.105
4565.806	111.256	6.05	1.231
4566.806	111.314	6.13	1.290
4567.823	111.374	6.22	1.325
4570.833	111.549	6.33	1.373

RADIUS AND LUMINOSITY

The radial velocity-curve was integrated over time to give displacements. The mean velocity (-7.0 km/sec) was assumed to be the systemic velocity, and, for an assumed limb darkening coefficient of $3/5$, a correction factor⁷ of $24/17$ was applied to the velocities.

Eighteen pairs of phases of equal color and with a light difference of more than 0.1 mag. were chosen. The bumps on the decline of the visual light-curve (Fig. 1) were smoothed out. For each pair of phases the ratio of surface areas was obtained from the light-curve and the difference in radii was taken from the displacement curve. With the equations used by Stebbins,⁸ eighteen determinations of the mean radius were then made. These radii, weighted according to the difference in light, yielded a mean radius of $(49.8 \pm 2.9) \times 10^6$ km. This value is approximately the same as Stebbins' radius of $(47 \pm 2) \times 10^6$ km. for η Aquilae, for which the period is only 7.18 days. The minimum and maximum radii for Y Oph are 47.1×10^6 and 52.5×10^6 km.

The observed colors (corrected for color excess) were converted to spectral types¹ and then to effective temperatures by using a correlation given by Keenan and Morgan.⁹ The mean spectral type and effective temperature are G0.2 and 4920°. This temperature and the above mean radius yield a mean absolute bolometric magnitude of -4.01 . A supergiant of this mean type would have a bolometric correction¹⁰ of -0.43 mag., which leads to a median absolute photographic magnitude of -2.92 . The Harvard period-luminosity relation,¹¹ corrected by -1.50 mag., would predict a median absolute photographic magnitude of -3.93 for this period. Y Oph is therefore 1.01 mag. fainter than a normal 17-day cepheid. Or, in other words, Y Oph has the intrinsic brightness of a normal cepheid of one-fourth its period.

This method is fairly sensitive to observational errors. Errors of 0.01 mag. in the color or 0.02 mag. in light may each produce up to 12 percent error in the radius or 0.26 mag. in the computed luminosity.

DISCUSSION

Since Y Oph is the only known 17-day cepheid with such small ranges in light, color, and velocity, we know very little about the relative frequency of stars of this kind. It may be that many similar stars with smaller periods and ranges have been overlooked. This star does not appear to be a population II variable because (1) it has a small mean radial velocity and low

galactic latitude ($+9^\circ$), (2) it is later in spectral type than W Virginis and does not have a typical W Virginis light-curve, and (3) it shows no hydrogen emission.

For a ratio of photographic absorption to color excess of 3, we derive a distance of 540 parsecs in the direction of galactic longitude 348° .

SUMMARY

A new radial velocity-curve is given for the 17-day anomalous cepheid Y Ophiuchi and is compared with concurrent photo-electric data by O. J. Eggen. An application of Wesselink's method yields a mean radius of 49.8×10^6 km. and a median photographic absolute magnitude of -2.92 . The latter quantity is 1.0 mag. fainter than the corrected Harvard period-luminosity relation would predict.

I wish to thank Dr. Olin J. Eggen for the use of his photo-electric data and both Drs. Eggen and Stebbins for reading the manuscript and making suggestions. I am also obliged to Per Olof Lindblad for some of the calculations involved in this paper.

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² *B.A.N.*, **10**, 91, 1946, No. 368.

³ S. Albrecht, *Lick Obs. Bull.*, **4**, 130, 1907, No. 118.

⁴ R. F. Sanford, *Ap. J.*, **81**, 140, 1935; *Mt. W. Contr.*, No. 509.

⁵ H. L. Johnson and W. W. Morgan, *Ap. J.*, **117**, 313, 1953; *McDonald Contr.*, No. 216.

⁶ O. J. Eggen, *A. J.*, **114**, 141, 1951; *Lick Obs. Contr.*, Ser. II, No. 37.

⁷ I. A. Gettings, *M.N.*, **95**, 141, 1934.

⁸ *Pub. A.S.P.*, **65**, 118, 1953.

⁹ *Astrophysics*, edited by J. A. Hynek (McGraw-Hill Book Company, Inc., New York, 1951), p. 20.

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¹¹ H. Shapley, *Proc. Nat. Acad. Sci.*, **26**, 541, 1940.