1983Ap&SS..93..271E

THE PHOTOMETRIC PERIOD OF 39 AY CETI

J. A. EATON[a], D. S. HALL[a], and G. W. HENRY[a, b]

Dyer Observatory, Vanderbilt University, Nashville, Tennessee, U.S.A.

J. L. HOPKINS

Hopkins-Phoenix Observatory, Phoenix, Arizona, U.S.A.

K. KRISCIUNAS[c]

Krisciunas Observatory, San José, California, U.S.A.

H. J. LANDIS

Landis Observatory, Locust Grove, Georgia, U.S.A.

H. LOUTH

Louth Observatory, Sedro Woolley, Washington, U.S.A.

E. H. OLSEN

Copenhagen University Observatory, Tølløse, Denmark

T. R. RENNER

Scuppernong Observatory, Dousman, Wisconsin, U.S.A.

and

H. J. STELZER

Stelzer Observatory, River Forest, Illinois, U.S.A.

(Received 7 February, 1983)

Abstract. Photoelectric photometry obtained in 1971 and 1972 is compared with that obtained in 1980–81 and 1981–82 to derive a photometric period of $77\overset{d}{.}65$. JD 2444636.0 is an epoch of minimum light. The full amplitude has been as large as $0\overset{m}{.}18$ in *V*. Curiously, the mean light level has dropped by almost $0\overset{m}{.}2$ over the last ten years. This binary is additionally interesting because of the recently discovered white dwarf secondary component and because unpublished radial velocity measures of Fekel show a large (0.1) eccentricity and an orbital period ($57\overset{d}{.}1$) very different from our photometric period.

1. Introduction

AY Ceti (= 39 Ceti) was classified G5 III by Cowley and Bidelman (1979), who noted the spectrum showed weak to moderate Ca II emission. This fact, along with the variability first suspected by Cousins (1962) and later confirmed by Olsen (1974), made us think AY Cet is probably an RS CVn binary.

[a] Guest Observer, Kitt Peak National Observatory, operated by the Association of Universities for Research in Astronomy, under contract with the National Science Foundation.
[b] Now at McDonald Observatory, Fort Davis, Texas.
[c] Now at United Kingdom Infrared Telescope, Hilo, Hawaii.

Astrophysics and Space Science **93** (1983) 271–276. 0004–640X/83/0932–0271$00.90.

In this paper we present the photometry obtained in 1971 and 1972 by Olsen, but not yet published, and additional photometry obtained in the 1980–81 and 1981–82 observing seasons. With these data we can define the full range of the variability and determine the photometric period.

Walter and Bowyer (1981) measured $L_x = 1.5 \times 10^{31}$ ergs s^{-1} with the HEAO II satellite. More recently Simon *et al.* (1982) reported far-ultraviolet observations with the IUE and radio observations with the VLA which indicated the presence of a hot white dwarf companion. Unpublished radial velocity measures of Fekel (1982) define the orbital motion with a period of about 57 days and appreciable eccentricity.

2. Photometry

The photometry discussed in this paper is summarized in Table I. That of Olsen, obtained between 1971.86 and 1971.93 and between 1972.48 and 1972.70, was described already by Olsen (1974), Grønbech and Olsen (1976), and Grønbech *et al.* (1976). The later photometry, obtained between 1980.58 and 1981.10 and between 1981.75 and 1982.12, was made differentially with respect to the comparison star 34 Ceti. The number of nights is *m* and the number of individual observations is *n*.

The data themselves, in the form of eleven sets marked A through K in correspondence with Table I, have been sent to the IAU Commission 27 Archive for Unpublished Observations of Variable Stars (Breger, 1982), where they are available as file No. 123. The individual magnitudes in set A, though made in *y* of the *uvby* system, have been transformed to *V* of the *UBV* system. The behavior of the indices $b - y$, m_1, and c_1 is described by Olsen (1974). The individual differential magnitudes in sets B through K

TABLE I

Photometry of 39 AY Ceti

Observer	Telescope	*V*		*B*	
		m	*n*	*m*	*n*
1971–72					
A. Olsen	ESO Danish 50-cm	24	57		
1980–81					
B. Eaton	KPNO No. 4 16-in	13	25		
C. Henry	Dyer 24-in	14	41	3	9
D. Henry	KPNO No. 4 16-in	16	46		
E. Hopkins	Hopkins 8-in	6	18		
F. Louth	Louth 11-in	2	6		
1981–82					
G. Krisciunas	Krisciannas 6-in	1	3		
H. Landis	Landis 8-in	10	29		
I. Louth	Louth 11-in	1	3		
J. Renner	Scuppernong 10-in	6	20		
K. Stelzer	Stelzer 14-in	2	7		

have been transformed differentially to ΔV, where Δ is in the sense variable minus comparison. Only set C contains a few ΔB observations; in the other sets a mean value of $\Delta(B-V) = -0\overset{m}{.}49$ was used in computing the corrections for extinction and transformation.

3. The Photometric Period

To provide one estimate of the photometric period we used a period-finding program similar to that of Lafler and Kinman (1965), applying it to nightly means of the ΔV magnitudes in sets B through K. The result was $77\overset{d}{.}68 \pm 0\overset{d}{.}05$.

To provide another estimate, we matched the recent ΔV observations (from 1980–81 and 1981–82) with the early V observations (from 1971 and 1972). The maxima, well defined in both light curves, could be brought into coincidence with a vertical shift of $5\overset{m}{.}76$. The falling branches then could be brought into coincidence with a period of $77\overset{d}{.}62 \pm 0\overset{d}{.}05$.

For predicting future behavior of AY Cet we propose the ephemeris

$$\mathrm{JD} = 2444636.0 + 77\overset{d}{.}65E\,, \tag{1}$$

where the period is a mean of the above two estimates and the initial epoch is a recent time of minimum light. Figures 1 and 2 show the nightly means from set A and from sets B through K, respectively, plotted vs phase computed with Equation (1).

4. Discussion

The total amplitude of the nearly sinusoidal light curve, defined most completely in Figure 2, is $0\overset{m}{.}18$ in V. Closer inspection of Figure 2 shows that the minimum in 1981–82 may have been about $0\overset{m}{.}05$ shallower than it was in 1980–81.

In comparing the light curve in Figure 1 with that in Figure 2 we noted one puzzle. To compare the first (determined without a comparison star) with the second (determined with a comparison star) we need to know how bright the comparison star 34 Cet was. The catalogue of Nicolet (1978) gives $V = 5\overset{m}{.}94$. As a check Eaton determined its brightness in 1981, at the same time he obtained the data in set B; based on intercomparisons with about 20 standards of the UBV system, he found $V = 5\overset{m}{.}94$ also. The maximum brightness of AY Cet in Figure 2 is $\Delta V = -0\overset{m}{.}41$, which corresponds to $V = 5\overset{m}{.}53$. The maximum brightness of AY Cet in Figure 1, however, is $V = 5\overset{m}{.}35$. Apparently, therefore, AY Cet has become about $0\overset{m}{.}18$ fainter over the last ten years. Such a large change in mean brightness, comparable to the total amplitude of the light curve, is somewhat remarkable.

Four Mt. Wilson radial velocities published by Abt (1970) ranged from -11.8 to -27.4 km s^{-1}, giving the first hint that this star may be a binary. Fourteen spectrograms obtained recently by Fekel (1982) indicated an orbital period of $57\overset{d}{.}1 \pm 0\overset{d}{.}1$ and an orbital eccentricity of 0.1. His period-finding program revealed no evidence of a period at or near 77 days. If this difference between the orbital period ($57\overset{d}{.}1$) and the

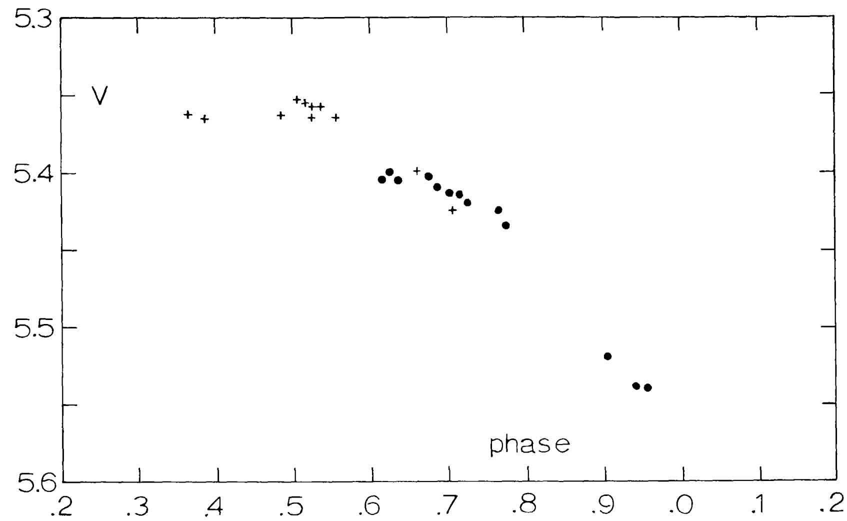

Fig. 1. The light curve of 39 AY Ceti based on phtometry from 1971 (filled circles) and 1972 (plusses). The ordinate is V magnitude. Phase is computed with the ephemeris in Equation (1).

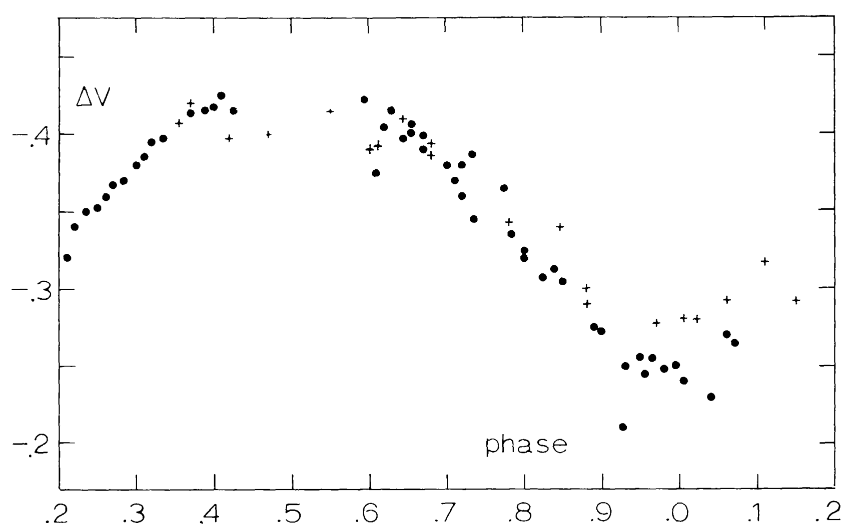

Fig. 2. The light curve of 39 AY Ceti ten years later. Filled circles are from the 1980–81 season, plusses from 1981–82. Here the ordinate is differential V magnitude, where Δ is the sense variable minus comparison. The full amplitude is about $0\overset{m}{.}18$ but seems to have been less in 1981–82. Phase is the same as in Figure 1.

photometric period ($77\overset{d}{.}65$) is confirmed, then we have an example of clearly non-synchronous rotation.

According to Hall (1981) the fact that $P(\text{orb.}) \approx P(\text{phtm.})$ in virtually all of the variable RS CVn binaries indicates that synchronous rotation is the rule, the only well-established example of rotation non-synchronous by more than a few percent being λ Andromedae (Boyd *et al.*, 1983). Although orbital eccentricity cannot be a factor in explaining non-synchronous rotation in λ And, for which Lucy and Sweeney (1971) considered the orbit circular, it could be a factor in the case of AY Cet and several other

TABLE II

Rotating spotted stars in binaries with eccentric orbits

Binary	e	P(orb.)	P(phtm.)	P(phtm.)/P(orb.)	References
λ And	0.04	20ᵈ52	53ᵈ95	2.63	Boyd *et al.* (1983)
54 Cam	0.11	11.08	10.17	0.92	Mekkaden *et al.* (1982)
BM Cam	0.35	80.17	82.8	1.03	Eaton *et al.* (1980)
BY Dra	0.49	5.98	3.83	0.64	Vogt (1981)
AY Cet	0.1	57.1	77.65	1.36	This paper

binaries. Table II lists several examples of rotating spotted stars in binaries with eccentric orbits. Understanding non-synchronous rotation in binaries like these and the role which orbital eccentricity might play will be a challenge for the future.

We now know of two detached binaries which contain a white dwarf along with a late-type star which is heavily spotted and chromospherically active. The other in V471 Tauri (Rucinski, 1981), the orbital period of which is shorter by two orders of magnitude! It will be interesting to see if white dwarfs can be found in any single-lined RS CVn binaries of intermediate period.

Acknowledgements

D.S.H. thanks NASA for supporting his part of this work with Research Grant NSG-7543. H.J.L., H.L., and T.R.R. wish to acknowledge their membership in the AAVSO. E.H.O. acknowledges the participation of the late Dr Bent Grønbech in the acquisition of the 1972 data. And all of us are grateful to Dr Francis C. Fekel for making his results available in advance of publication.

References

Abt, H. A.: 1970, *Astrophys. J. Suppl.* **19**, 387.

Boyd, R. W., Eaton, J. A., Hall, D. S., Henry, G. W., Genet, R. M., Lovell, L. P., Hopkins, J. L., Sabia, J. D., Krisciunas, K., Chambliss, C. R., Detterline, P. K., Landis, H. J., Louth, H., Renner, T. R., Skillman, D. R., and Montle, R. E.: 1983, *Astrophys. Space Sci.* **90**, 197.

Breger, M.: 1982, *Inf. Bull. Var. Stars*, No. 2248.

Cousins, A. W. J.: 1962, *Monthly Notices Astron. Soc. South Africa* **21**, 20.

Cowley, A. P. and Bidelman, W. P.: 1979, *Publ. Astron. Soc. Pacific* **91**, 83.

Eaton, J. A., Hall, D. S., Henry, G. W., Landis, H. J., McFaul, T. G., and Renner, T. R.: 1980, *Inf. Bull. Var. Stars*, No. 1902.

Fekel, F. C.: 1982, private communication.

Grønbech, B. and Olsen, E. H.: 1976, *Astron. Astrophys. Suppl.* **25**, 213.

Grønbech, B., Olsen, E. H., and Strömgren, B.: 1976, *Astron. Astrophys. Suppl.* **26**, 155.

Hall, D. S.: 1981, in R. M. Bonnet and A. K. Dupree (eds.), *Solar Phenomena in Stars and Stellar Systems*, D. Reidel Publ. Co., Dordrecht, Holland, p. 431.

Lafler, J. and Kinman, T. D.: 1965, *Astrophys. J. Suppl.* **11**, 216.

Lucy, L. B. and Sweeney, M. A.: 1971, *Astron. J.* **76**, 544.

Mekkaden, M. V., Raveendran, A. V., and Mohin, S.: 1982, *Inf. Bull. Var. Stars*, No. 2218.
Nicolet, B.: 1978, *Astron. Astrophys. Suppl.* **34**, 1.
Olsen, E. H.: 1974, *Inf. Bull. Var. Stars*, No. 925.
Rucinski, S. M.: 1981, *Acta Astron.* **31**, 37.
Simon, T., Fekel, F., and Gibson, D. M.: 1982, *Bull. Am. Astron. Soc.* **14**, 982.
Vogt, S. S.: 1981, *Astrophys. J.* **250**, 327.
Walter, F. M. and Bowyer, S.: 1981, *Astrophys. J.* **245**, 671.