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THE PERIOD SHORTENING OF RY SAGITTARII

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ABSTRACT

Using 10 000 visual estimates taken from the literature and obtained between 1897 and 1977, the 39-day period, 0.6-mag amplitude cycle of RY Sgr is analyzed. 2800 averages were made with these estimates and 460 dates of maxima and an equal number of minima were determined. A secular period change is found analyzing these dates. In the time interval studied the period change is from 39.4 to 38.2 days. Superimposed on this variation is a sinusoidal phase change suggesting a periodicity of about half a century. On top of these two phenomena there are phase shifts of about 10 days that happen rather randomly. These phase shifts seem to be associated with the deep minima of this R CrB-type variable. The meaning of the secular period change is discussed and alternatively explained as mass loss or rapid evolution changes. A possible explanation of the random phase shifts is given.

I. INTRODUCTION

The R CrB-type variable star RY Sgr has been known to vary in a cyclic way since Jacchia's (1933) publication of his own visual observations covering the interval 1920–1932.

This cyclic variation has a Cepheid-like light curve with 0.6-mag amplitude and a 39-day period. Jacchia also found that the 39-day variations remained active even in the middle of the deep minima often suffered by this star.

Later Alexander *et al.* (1972) studied the star photoelectrically and spectroscopically, confirming all of Jacchia's results and at the same time establishing firmly the pulsating nature of the variation.

More recently Pugach (1977) studied the connection of this cyclic variation with the onset of the deep minima and detected a period shortening of 0.9 days in 40 yr. He used observations covering the interval 1926–1977, but he omitted 168 cycles due to lack of observations.

Marraco and Milesi (1980) presented a preliminary report of the period change using the same material that is considered here.

Kilkenny (1982), using the same period interval as Pugach but with some additional observations to close the above-mentioned gap, reaches some conclusions that are essentially similar to those that we present here.

II. THE DATA FROM THE LITERATURE

Although since 1751 (Lacaille 1847) there have been some scattered observations of this star in the literature, the first continued series are those published by Innes (1903, 1907) that cover the interval 1897–1902.

Starting in 1913 the American Association of Variable Stars Observers (AAVSO) have had a continued series of observations that extended to 1977. These observations have been published sometimes as individual observations and sometimes as five-day means. Several authors prepared these observations for publication and the results were published in different professional and popular magazines. The AAVSO observations were reported by: Olcott (1913–1919), Woods (1919), Eaton (1919–1924), Walker (1922), Campbell (1925–1935, 1938–1948), Mayall (1949–1966, 1972), and Mattei (1977).

The Royal Astronomical Society of New Zealand Variable Star Section (RASNZ VSS) has a continued series of observations that cover the interval 1947–1973. These visual estimates have been reported by Bateson (1947–1971, 1974–1975, 1977) and they are presented as individual estimates.

The Asociacion Argentina "Amigos de la Astronomia" (AAAA) has published five-day means of their observations covering the years 1964–1966. They were reported by Forte *et al.* (1966).

Some photoelectric visual observations were reported by Bateson (1977) and some others published by Eggen (1970), Alexander *et al.* (1972), Landolt (1972), and Lee (1973). All these observations are very recent (after 1962) and with some exceptions are rather scattered.

III. DATA REDUCTION PROCEDURES

All the individual estimates were listed together and combined in five-day means. When three or more observations were available to form each mean, the standard

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deviation was computed, too. The means were categorized in six types according to their standard deviations. In addition we had single observations and two estimate means.

The AAVSO means were categorized similarly but only on the basis of the number of estimates involved in each mean. For this purpose a single-estimate error of about 0.15 mag was adopted and the errors of the means computed accordingly. Some AAVSO means were already categorized in weights.

Preliminary light curves were then drawn for those time intervals in which the five-day means from the AAVSO and those obtained from our own averages of RASNS VSS estimates were both abundant. The match of both sets of observations to the resulting light curve was judged and solely on this basis the system of categories was unified.

The five-day means from the AAAA were treated similarly to those of the AAVSO.

All visual estimates, now in the form of a consistent set of five-day means, were plotted and the light curve drawn by free hand having in mind the weight of each point. In the case of discrepancies, errors in the averages were sought after, and in some cases corrected as they were found.

The photoelectric observations were plotted alongside the visual estimate means, but displaced two magnitudes in the ordinate. Only in the case when they were frequent enough was the photoelectric light curve drawn.

The dates of maxima and minima were read from the light curves in those parts where the variation was clearly marked. The estimated error of these dates ranges from two days, when the light curve is well defined, to about ten days in some ill-defined parts.

Dates of maxima and minima were also obtained from the photoelectric light curves and also from the observations plotted in the figure on p. 244 in Jacchia (1933). It was carefully checked that Jacchia's observations were not sent to AAVSO; that is, that they conform to an independent source of information.

The three sets of maxima and minima were given equal weight and averaged. The differences between them were small, and nonsystematic.

Figure 1 shows a portion of the light curve in a well-observed region.

A listing of the dates of maxima and minima can be obtained upon request from one of the authors (H.G.M.).

IV. DATA ANALYSIS

Maxima and minima were treated separately. Starting with the well-observed parts of the light curve, the dates of maxima (and minima) were arranged sequentially. A linear-least-square fit was then applied to those portions where we were sure that the sequence was correct. That is, no interleaving maximum (or minimum) was missing or was in excess. The different portions of the light curve were then interconnected carefully into a single table of dates of maxima (and minima). The linear-least-square fit was applied then to this table and $O-C$ plots were produced. Improper fits between the different portions were detected as abrupt 39-day steps in the $O-C$ plots.

Figure 2 shows the $O-C$ plots resulting from the linear-least-square fits.

It is clear that the secular period variation found by Pugach (1977) using a shorter time base dominates the general trend of the residuals. A quadratic least-square fit was then applied to the same material. The results from these fittings are

$$\text{maximum} = 2433670 + 38.6056*E - 0.000784*E**2,$$

$$\text{minimum} = 2433690 + 38.6087*E - 0.000763*E**2.$$

The differences between maxima and minima can be used to estimate the errors and the instantaneous period can be expressed as

$$\text{period} = 38.607 - 2*0.00077*E$$

$$\text{error} \quad 0.001 \quad 0.00001.$$

That means that the instantaneous periods in 1897, 1926 [the first epoch of Pugach's (1977) observations] and 1977 were 39.3, 39.0, and 38.2 days, respectively. The period decrease rate of Pugach (1977) is then confirmed and slightly corrected with a longer time base to 1.1 days in 80 yr.

Using only 231 minima between 1926 and 1978, Kilkenny (1982) finds a value of (-51 ± 2)E $-$ 5 days every period. Using the same units our own value is

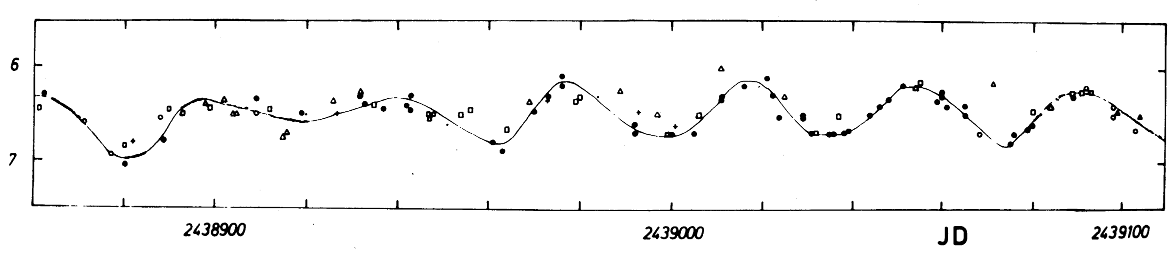

FIG. 1. Light curve of RY Sgr. The different symbols indicate different sources of the data used for the mean values plotted.

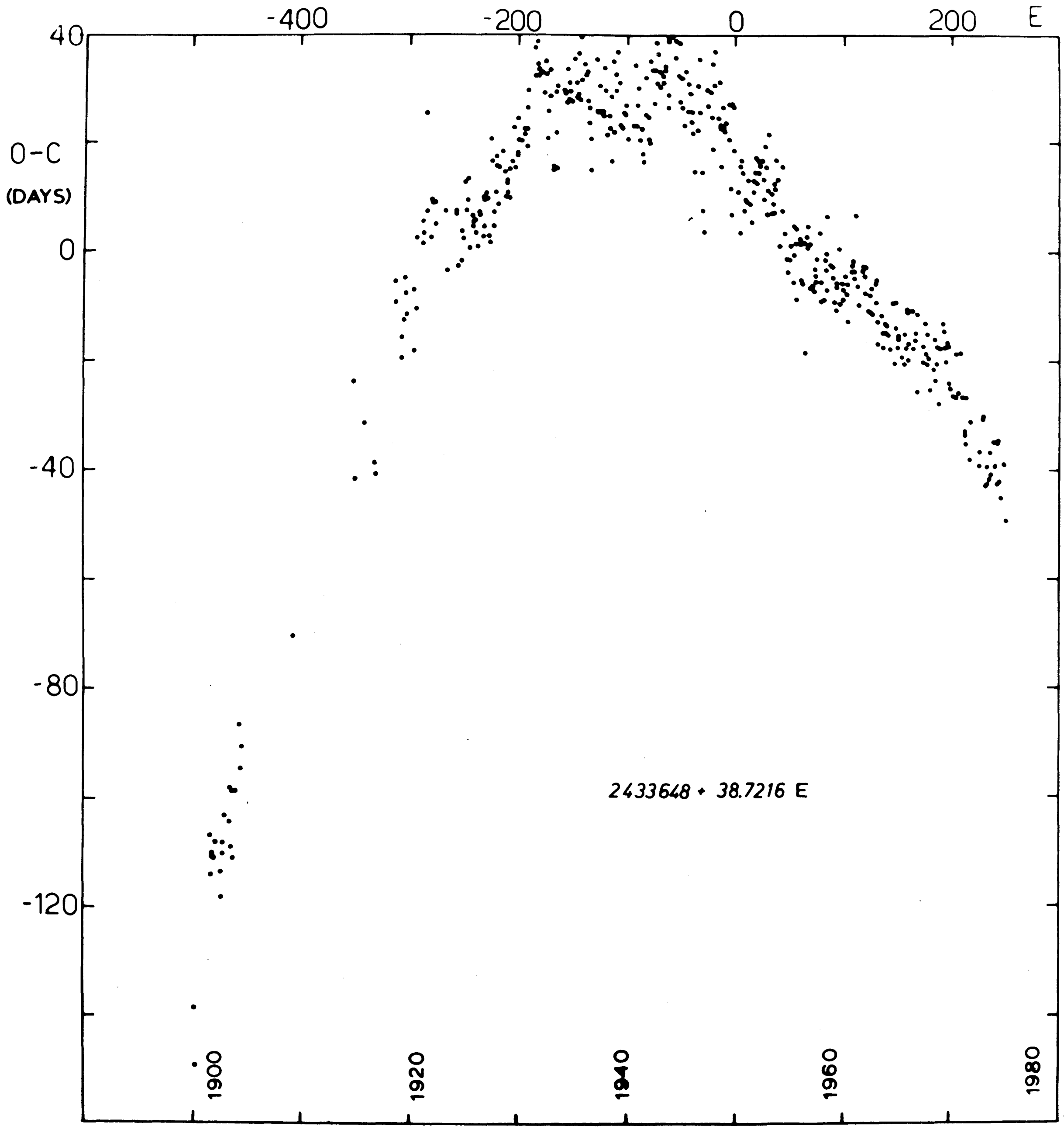

FIG. 2(a). $O - C$ residual plot for the linear solution (maxima).

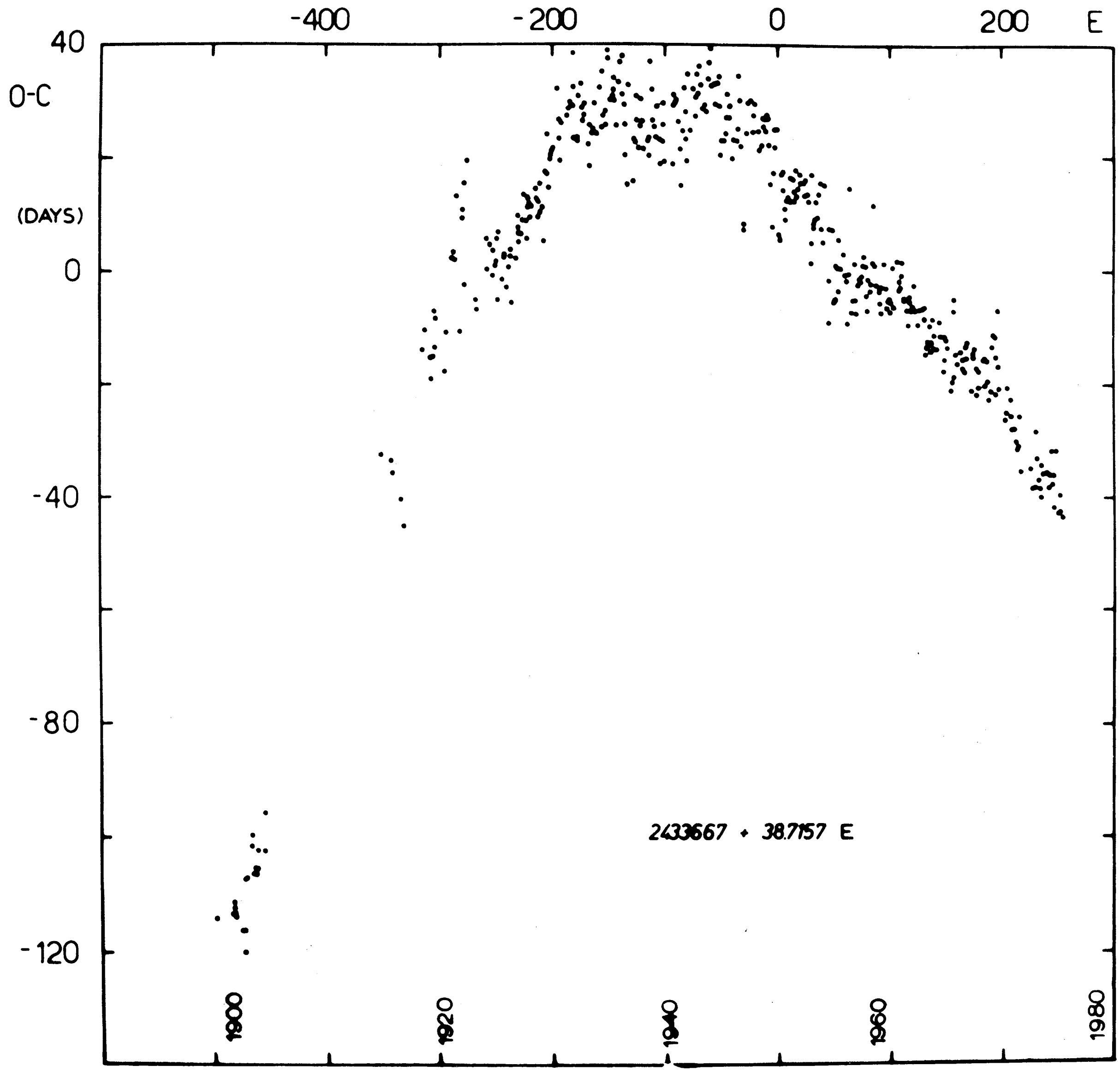

FIG. 2(b). Same as Fig. 2(a), but for the minima.

$(-77 \pm 1)E-5$.

The errors quoted in Sec. III are clearly visible in Fig. 2. They are also present in the residuals obtained after removing the secular period variation where they appear as noise in the $O-C$ plots. In order to look for features not narrower than three years, the residuals were smoothed with a moving average technique. Each residual was replaced by a least-square fit involving the preceding and the following 32 values. The weight of each value in final average was selected in a symmetrical bell-shaped distribution, the half-width of which is about 32 values. That means that features narrower than $32 \times 39 = 1248$ days (~ 3 yr) were washed out. Figure 3 shows the resulting smoothed $O-C$ plots.

Two features are present in Fig. 3: (i) a sinusoidal phase shift with a period of about 50 yr; (ii) phase shifts of about 10 days that happen rather randomly in time. The lower part of Fig. 3 also has included a small-scale plot of the grand design light curve of RY Sagittarii showing all the known deep minima.

Several simulations of the raw (nonsmoothed) residuals were performed through random number generation. Close matches were obtained in mean values, standard deviations, and in the appearance of the plots. These simulated sets of residuals were then smoothed with exactly the same method as the true raw residuals. All sets of smoothed residuals were treated equally and correlation was sought between the dates of the maxima and minima of the phase shifts and the dates of the known deep minima of the light curve of RY Sagittarii. All the correlations that were found proved not to be significant as they happened with equal frequency and significance level with the simulated sets of $O-C$ residuals as in the true set.

The only real features of the residual plots seem to be the broad maxima at dates (epochs): 1921 (-280), 1933 (-170), 1945 (-60), and 1974 ($+210$). The second and the fourth are double maxima. Although the dates do not match exactly, it must be remarked that the minima of the light curve that reach fainter than 12 mag seem to happen in pairs approximately centered at dates (epochs): 1920 (-300), 1933 (-170), 1946 (-40), and 1970 ($+180$).

V. DISCUSSION

Two possible causes were investigated for the period shortening: (a) rapid evolution and (b) mass loss.

a) Rapid Evolution

Schonberner (1977) gives evolutionary tracks for helium stars of masses between $1M_\odot$ and $0.65M_\odot$. Assuming approximate values of $1M_\odot$ and 3.85 for the mass and $\log T_{\rm eff}$ of RY Sgr (Hill *et al.* 1981) the $1M_\odot$ track of Schonberner can be used to predict a $\log g$ increase of 0.3 in time intervals as long as 1.E4 yr or as short as 2.E3 yr. The time interval depends on the exact location of the star in the track since evolution speeds up considerably at $\log T_{\rm eff} = 3.9$.

With the usual assumption that P*SQRT(ρ/ρ_0) = const. we find that the predicted period change is $\dot{P} = -3.E-5$ days every day for the fast side of the evolutionary track and $\dot{P} = -5.E-6$ days every day for the slow side. The observed period change as determined in Sec. IV is $-0.001\,54$ days every period or $\dot{P} = -4.E-5$ days every day.

Using exactly the same assumptions, Kilkenny (1982) shows that a fit to the observed period change is possible also for a $1M_\odot$ star. Note that Kilkenny's k is $\dot{P}/2$.

b) Mass Loss

With the same assumption the mass loss can be considered the cause of period shortening. Adopting again $1M_\odot$ for the mass, the mass-loss rate necessary for obtaining the observed $\dot{P}$ is $\dot{M} = 1.5E-3\ M_\odot$/yr. In this calculation it was supposed that the radius remains fixed during the mass loss.

Wood (1976) states that a possible mechanism of mass loss is the occasional ejection of surface layers driven by the radial pulsation. Pugach (1977) observationally determined that the onset of the deep light curve minima of RY Sgr is always located in the same phase of the 39-day period.

The possibility exists that the large phase shifts mentioned in Sec. IV are caused by the direct observation of the layers next to the surface ones after one of these ejections was considered and subsequently discarded because: (a) As the pulsation proceeds from inside, the phase shifts would then be negative. (b) For obtaining a 10-day phase shift it would be necessary to remove 0.15 R from the star and this includes the ionization zones (Wood 1976, Figs. 2 and 3). (c) The reaccommodation of the internal structure of the star after the mass loss is presently unknown and is possibly very fast. (d) Trimble (1972) showed that the pulsation grows to a stable situation in short time intervals compared to the duration of the deep minima.

Kilkenny (1982) considers the possibility that the phase shifts are caused by mass loss and rules out this hypothesis on the basis of the improbably high mass-loss rate necessary.

VI. CONCLUSIONS

The pulsation period of RY Sgr is shortening at the very fast rate of $-0.000\,04$ days every day.

The fast evolution of the post-giant phase of helium stars seems to be one of the possible causes of this period change. The same conclusion was reached independently by Kilkenny (1982) but using exactly the same line of reasoning.

The mass-loss rate necessary to account for the observed period shortening is large enough for the star to vanish in less than a millenium. This result could be revised if detailed calculations of the structure of the star during mass loss became available.

In any case both hypotheses indicate that lifetimes of

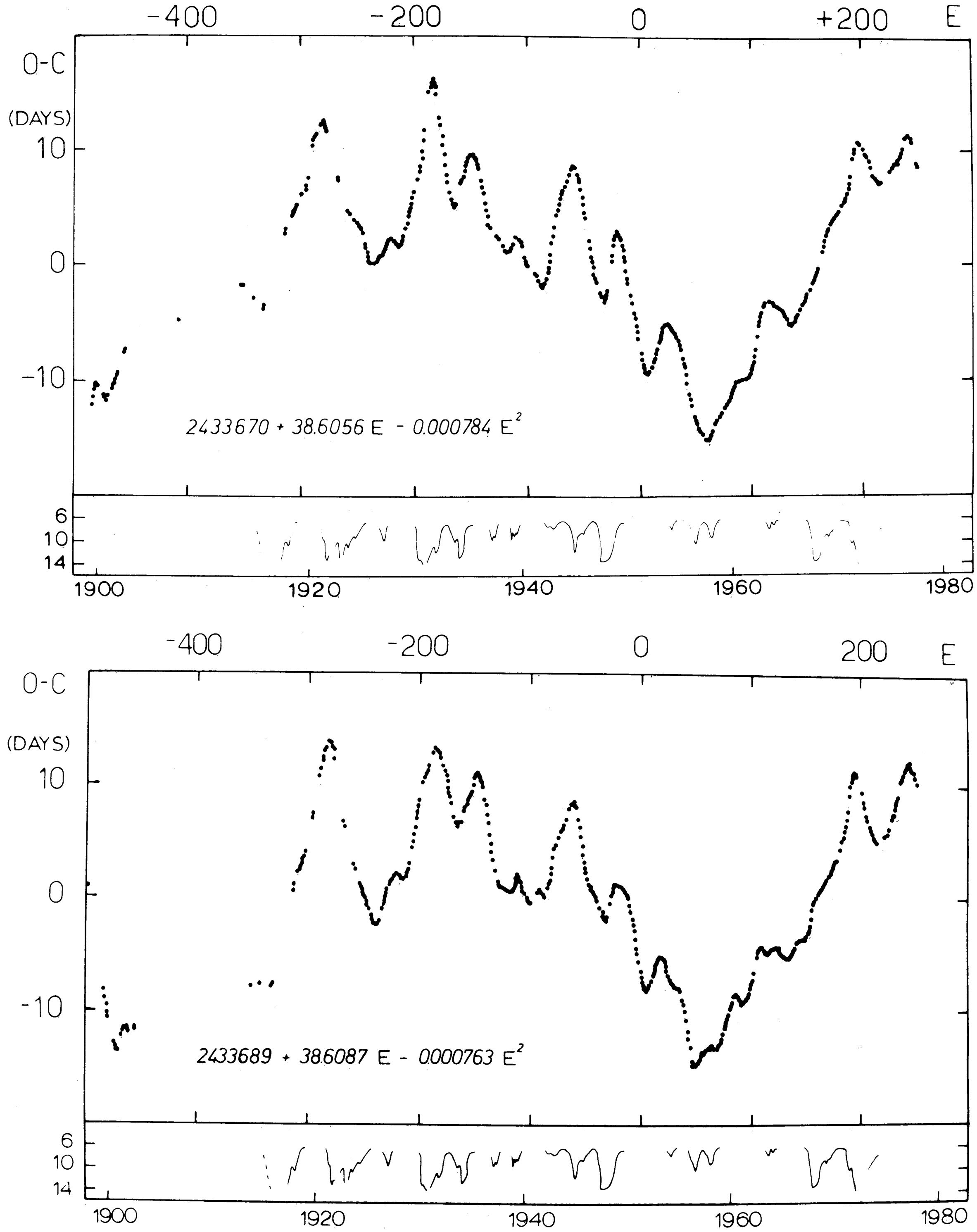

FIG. 3. Smoothed $O - C$ residual plot of the quadratic solution. See the text for the smoothing technique. In the lower part the observed light curve in the same time interval is reproduced for comparison. Part (a) refers to the maxima and (b) to the minima.

R CrB-type stars as pulsating stars are very short.

There is a weak indication that deep minima of the light curve may be connected with positive phase shifts of the pulsation. That is, that the phases temporarily happen later than the predicted date while the star is suffering the visible light fadings. This situation cannot be caused by the direct observation of the "new" star surface after the ejection of the surface layers.

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REFERENCES

Alexander, J. B., Andrews, P. J., Catchpole, R. M., Feast, M. W., Evans, L. T., Menzies, J. W., Wisse, P. N. J., and Wisse, M. (1972). Mon. Not. R. Astron. Soc. **158**, 305.

Bateson, F. M. (1947). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 36.

Bateson, F. M. (1948). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 37.

Bateson, F. M. (1949). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 44 and 46.

Bateson, F. M. (1950). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 47 and 48.

Bateson, F. M. (1951). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 52.

Bateson, F. M. (1952). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 53–55, 57–59.

Bateson, F. M. (1953). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 60–64.

Bateson, F. M. (1954). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 65.

Bateson, F. M. (1955). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 67–70.

Bateson, F. M. (1956). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 71, 73–75.

Bateson, F. M. (1957). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 76, 77, 81, and 83.

Bateson, F. M. (1958). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 84–86.

Bateson, F. M. (1959). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 89–93 and 95.

Bateson, F. M. (1960). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 98–100 and 106.

Bateson, F. M. (1961). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 109 and 110.

Bateson, F. M. (1963). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 111–113.

Bateson, F. M. (1964). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 114 and 115.

Bateson, F. M. (1965). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 116–118.

Bateson, F. M. (1966). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 120.

Bateson, F. M. (1967). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 127.

Bateson, F. M. (1968). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 133 and 134.

Bateson, F. M. (1970). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 147.

Bateson, F. M. (1971). R. Astron. Soc. New Zealand Var. Star Sec. Circ. 168 and 184.

Bateson, F. M. (1974). R. Astron. Soc. New Zealand Var. Star Sec. Publ. **1**, 33.

Bateson, F. M. (1975). R. Astron. Soc. New Zealand Var. Star Sec. Publ. **3**, 1.

Bateson, F. M. (1977). R. Astron. Soc. New Zealand Var. Star Sec. Circ. S77, 1.

Campbell, L. (1925). Pop. Astron. 33.

Campbell, L. (1926). Pop. Astron. 34.

Campbell, L. (1927). Pop. Astron. 35.

Campbell, L. (1928). Pop. Astron. 36.

Campbell, L. (1929). Pop. Astron. 37.

Campbell, L. (1930). Pop. Astron. 38.

Campbell, L. (1931). Pop. Astron. 39.

Campbell, L. (1932). Pop. Astron. 40.

Campbell, L. (1933). Pop. Astron. 41.

Campbell, L. (1934). Pop. Astron. 42.

Campbell, L. (1935). Pop. Astron. 43.

Campbell, L. (1938). Harv. Ann. 104.

Campbell, L. (1940). Harv. Ann. 107.

Campbell, L. (1945). Harv. Ann. 110.

Campbell, L. (1948). Harv. Ann. 116.

Eaton, H. O. (1919). Pop. Astron. 27.

Eaton, H. O. (1920). Pop. Astron. 28.

Eaton, H. O. (1921). Pop. Astron. 29.

Eaton, H. O. (1922). Pop. Astron. 30.

Eaton, H. O. (1923). Pop. Astron. 31.

Eaton, H. O. (1924). Pop. Astron. 32.

Eggen, O. J. (1970). Publ. Astron. Soc. Pac. **82**, 851.

Forte, J. C., Marraco, H. G., and Barone, M. A. (1966). Bol. Estrellas Variables **6**, 1.

Hill, P. W., Kilkenny, D., Schonberner, D., and Walker, H. J. (1981). Mon. Not. R. Astron. Soc. **197**, 81.

Innes, R. T. A. (1903). Ann. Cape Observatory **9**, 135B.

Innes, R. T. A. (1907). Astron. Nachr. **175**, 127.

Jacchia, L. (1933). Publ. Oss. Astron. Univ. Bol. **2**, 173.

Kilkenny, D. (1982). Mon. Not. R. Astron. Soc. (in press).

Lacaille, J. (1847). *Catalogue of Southern Stars* (British Association, London).

Landolt, A. U. (1973). Publ. Astron. Soc. Pac. **85**, 625.

Marraco, H. G., and Milesi, G. (1980). Bol. Asoc. Argentina Astron. **25**, 32.

Mattei, J. A. (1977). AAVSO private communication.

Mayall, M. W. (1949). Am. Assoc. Var. Star Observers Q. Rep. 1.

Mayall, M. W. (1950). Am. Assoc. Var. Star Observers Q. Rep. 2 and 3.

Mayall, M. W. (1951). Am. Assoc. Var. Star Observers Q. Rep. 4–8.

Mayall, M. W. (1952). Am. Assoc. Var. Star Observers Q. Rep. 9–16.

Mayall, M. W. (1953). Am. Assoc. Var. Star Observers Q. Rep. 17.

Mayall, M. W. (1956). Am. Assoc. Var. Star Observers Q. Rep. 18.

Mayall, M. W. (1957). Am. Assoc. Var. Star Observers Q. Rep. 19.

Mayall, M. W. (1958). Am. Assoc. Var. Star Observers Q. Rep. 20 and 21.

Mayall, M. W. (1959). Am. Assoc. Var. Star Observers Q. Rep. 22 and

23.
Mayall, M. W. (1960). Am. Assoc. Var. Star Observers Q. Rep. 24.
Mayall, M. W. (1962). Am. Assoc. Var. Star Observers Q. Rep. 25.
Mayall, M. W. (1964). Am. Assoc. Var. Star Observers Q. Rep. 26.
Mayall, M. W. (1966). Am. Assoc. Var. Star Observers Q. Rep. 27.
Mayall, M. W. (1972). Am. Assoc. Var. Star Observers Rep. **29**, 47.
Olcott, W. T. (1913). Pop. Astron. 21.
Olcott, W. T. (1914). Pop. Astron. 22.
Olcott, W. T. (1915). Pop. Astron. 23.
Olcott, W. T. (1916). Pop. Astron. 24.
Olcott, W. T. (1917). Pop. Astron. 25.
Olcott, W. T. (1918). Pop. Astron. 26.
Olcott, W. T. (1919). Pop. Astron. 27.
Pugach, A. F. (1977). Inf. Bull. Var. Stars. No. 1277.
Schonberner, D. (1977). Astron. Astrophys. **57**, 437.
Trimble, V. (1972). Mon. Not. R. Astron. Soc. **156**, 411.
Walker, A. D. (1922). Pop. Astron. **30**.
Wood, P. R. (1976). Mon. Not. R. Astron. Soc. **174**, 531.
Woods, I. E. (1919). Pop. Astron. **27**.