THE DECREASING PERIODS OF R AQUILAE AND R HYDRAE

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Abstract

Times of maximum light of the long period variables R Aquilae and R Hydrae have been fitted to parabolic elements corresponding to constantly decreasing periods. The fit is satisfactory for R Aquilae but not for R Hydrae.

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1. Introduction

Although Mira type variables are among the most common variable stars, there is still much work to be done in studying them. Most of these future projects involve special techniques or instrumentation. However, one area that is crucial in understanding these variables concerns their long-term optical behavior. Fortunately, this behavior can be monitored by observers with modest equipment. A study of the Mira variables R Aquilae and R Hydrae was done while I was a summer student research assistant at AAVSO Headquarters in 1981. These two variables are distinguished by decreasing periods, and my objectives were to examine the nature of this interesting long-term behavior, and to compute an ephemeris to be used in predicting future dates of maximum brightness for each star. The period changes may be due to luminosity changes resulting from a shell flash in the helium burning region of these stars (Wood 1975).

2. History of R Aquilae

R Aquilae was first observed by Argelander at Bonn, Germany, in 1856. The visual light curve is characterized by a rather rapid rise to maximum light followed by a slower decline to minimum. Figure 1 is the visual light curve of R Aquilae taken from AAVSO Report 30 (1975). Points represent 10 day means, beginning JD 2438295 and ending JD 2439294.

It is interesting to note that R Aquilae has been identified as an infrared source, and is also known to be a source of OH maser emission (Wilson et al. 1970). Infrared observations suggest that circumstellar dust shells may be present. These observations permit the radii and densities of the dust shells to be determined, allowing calculation of the rate of mass ejection (Gehrz and Woolf 1971). The detection of OH features is important because studies have suggested that the differences between the light curves of OH and non-OH Miras may indicate differences between their pulsational properties and may provide evidence for the mechanism of mass loss in these stars (Bowers and Kerr 1977).

3. Analysis of R Aquilae

My analysis of R Aquilae is similar to the method used by Schneller (1965) in his study of R Aquilae and R Hydrae. The first

*AAVSO summer student research assistant funded by Margaret W. Mayall Assistantship Program.

step in the analysis was to tabulate the dates of maxima. Since Argelander's first recorded maximum of R Aquilae in 1856, the star has proceeded through 156 cycles, with a cycle defined as the period from one maximum to the next maximum. Of these 156 cycles, dates of maxima were found for 126. These dates were obtained from Astronomische Nachrichten as listed by Muller and Hartwig (1920) for the 19th and early 20th century, and the published (Campbell 1955) and unpublished AAVSO data to the present. The recent unpublished data, from cycle 106 on, are given in Table I. Once the available dates of observed maxima were tabulated, they were compared with dates computed from a linear ephemeris of the form

$$t_n = t_o + P_m n, \tag{1}$$

in which we used Campbell's mean period, P_m = 306.2 days, and initial epoch, t_o = JD 2399170. The resulting values of O-C are plotted in Figure 2. If the O-C plot were a straight line, a constant period would be indicated, but the fact that it is nearly a parabola indicates that the period is changing at a nearly constant rate. This secular change can be represented by the following expression for the period at any cycle, n,

$$P_n = P_o + 2Qn, \tag{2}$$

where P_o equals the period at n = 0, and Q equals a constant term representing change of period.

A parabolic ephemeris can be derived by integrating the equation, $dt_n = P_n dn$, which gives

$$t_n = t_o + P_o n + Qn^2. \tag{3}$$

We fit this curve to the observed times of maxima in the following way. A parabola is forced through the origin and two later points on the O-C plot by solving simultaneous equations of the form:

$$(O-C)_n = an + bn^2 \tag{4}$$

for a and b. Figure 2 shows the computed parabola, which intersects the x-axis on the descending branch at n'. The mean period in the interval o to n' is P_m and this value occurs at n = n'/2, so we have from equation (2)

$$P_m = P_o + n'Q. \tag{5}$$

Correspondingly, the maximum difference, $(O-C)_{max}$, between the linear and the parabolic ephemerides given by equations (1) and (3) occurs at n = n'/2, so we have

$$(O-C)_{max} = -Q(n'/2)^2. \tag{6}$$

From this we find the secular term

$$Q = -4(O-C)_{max}/(n')^2. \tag{7}$$

4. Results of R Aquilae Analysis

In the analysis of R Aquilae, the following values were obtained:

P_m = 306.2 days — Q = 0.233188 day

$(O-C)_{max}$ = 1765 days — P_o = 346.77 days

n' = 175.

Therefore, the current ephemeris of R Aquilae is

$$t_n = \text{JD } 2399170 + 346.77n - 0.233188n^2. \qquad (8)$$

To test the accuracy of this ephemeris, a second O-C plot was constructed. Figure 3 is a plot of observed maximum (O) minus the ephemeris maximum (C) predicted for a particular cycle (n). As can be seen in the plot, the relatively small amplitude of the curve indicates that this ephemeris is satisfactory.

5. History of R Hydrae

R Hydrae has the distinction of being the third long period variable to be discovered, predated only by o Ceti (Mira) and χ Cygni (Burnham 1978). Although Maraldi is credited as having discovered R Hydrae in 1704, it was seen by Hevelius in 1662 but not recognized by him as a variable. The visual light curve of R Hydrae varies from cycle to cycle as can be seen by Figure 4, taken from AAVSO Report 30 (1975). This variation may be explained by the existence of irregularities in the pulsational mechanism of the star itself. The amplitude of the curve varies also, maintaining an average value of 5.0 magnitudes.

6. Analysis of R Hydrae

Although dates of maxima were found extending back to the early 18th century, early data are very scattered and of doubtful quality. With this in mind, I found that good data exist only back to 1843, starting with cycle 131 (epoch JD 2393451). From cycle 131 to the present, 96 cycles were found to have observed dates of maximum. These dates were obtained from Astronomische Nachrichten, as listed by Muller and Hartwig (1918) for the 19th and early 20th century, and the published (Campbell 1955) and unpublished AAVSO data to the present. The recent unpublished data, from cycle 223 on, are given in Table II.

Once tabulated, it was necessary to compute dates of maxima as was done for R Aquilae. For R Hydrae, Campbell gives a mean period of 407.2 days, which constituted the step size used in calculating maxima from cycle 131. Figure 5 contains the O-C plot for R Hydrae with the superimposed parabola computed in the same manner as for R Aquilae. The plotted data show a generally parabolic shape, indicating a secular period change, except in the interval from cycle 182 to 210 (March 1905 to August 1935), when the O-C values declined by almost 90 days. Following this interval, the O-C's rose once more before finally beginning their current, almost linear, decline. The cause of this behavior is unknown.

As was done for R Aquilae, Schneller's method was used in the analysis of R Hydrae. The same equations were used in the same manner except that the (n) term is replaced by (n-131), because the analysis of the data began with cycle 131.

7. Results of R Hydrae Analysis

In the analysis of R Hydrae, the following values were obtained:

P_m = 407.2 days   Q = 0.3125 day

$(O-C)_{max}$ = 1620 days P_o = 452.2 days

n' = 275.

Therefore, the current ephemeris of R Hydrae is

$$t_n = \text{JD } 2394351 + 452.2(n-131) - 0.3125(n-131)^2. \qquad (9)$$

To test the accuracy of this ephemeris, a second O-C plot was constructed. Figure 6 is a plot of observed maximum (O) minus the ephemeris maximum (C) predicted for a particular cycle (n). The fit is unsatisfactory, as evidenced by the abundance of points that are more than 100 days in error. The deviation first becomes apparent during cycle 185, which is also the point on the O-C curve at which the deviation begins. Perhaps a linear fit might be obtained for the descending branch of the O-C curve in Figure 5. This possibility warrants further study, as it is apparent that the standard parabolic model fails as R Hydrae undergoes anomalous behavior.

8. Summary

My investigation into the long-term behavior of R Aquilae and R Hydrae has revealed that both stars possess decreasing periods. Using the method of Schneller, I was able to determine a satisfactory parabolic ephemeris for R Aquilae. When the same process was applied to R Hydrae, however, the ephemeris was definitely inadequate.

9. Acknowledgements

I would like to thank the AAVSO observers whose continual monitoring of these stars has made this study possible.

I would like to thank Mrs. Janet A. Mattei, Director of the AAVSO, for her advice and guidance during this project.

I would also like to express my gratitude to Dr. Edward Guinan of Villanova University, who enabled me to participate in the Margaret Mayall Summer Research Assistantship program at AAVSO Headquarters.

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TABLE I

Unpublished AAVSO Data for Maxima of R Aquilae

Cycle	JD(Max)	Mag.(Max)	JD(Min)	Mag.(Min)
106	2432960	6.3	2433140	11.2
107	2433269	6.2	2433422	10.8
108	2433555	5.4	2433748	11.6
109	2433868	6.8	2434031	12.0
110	2434164	6.4	2434337	11.8
111	2434466	7.0	2434630	11.8
112	2434766	7.0	2434934	11.5
113	2435057	6.5	2435227	(11.4
114	2435360	6.6	2435529	----
115	2435647	6.3	2435819	11.2
116	2435941	6.3	2436109	11.3
117	2436228	7.1	2436400	11.5
118	2436527	6.5	2436700	11.1
119	2436820	6.0	2436994	(10.9
120	2437116	7.0	2437286	(11.7
121	2437415	6.6	2437581	11.4
122	2437708	6.8	2437862	11.4
123	2437988	6.2	2438160	11.3
124	2438283	6.6	2438456	11.5
125	2438580	6.1	2438756	(11.2
126	2438885	6.4	2439038	11.2
127	2439161	6.0	2439332	11.3
128	2439460	6.2	2439630	11.4
129	2439744	6.2	2439910	(11.0
130	2440041	6.3	2440211	11.0
131	2440333	6.5	2440496	11.0
132	2440620	6.7	2440780	11.2
133	2440902	6.2	2441070	11.0
134	2441185	6.5	2441359	11.5
135	2441475	6.8	2441642	11.2
136	2441752	5.9	2441918	11.0
137	2442035	6.2	2442195	10.9
138	2442322	6.5	2442485	11.0
139	2442600	6.1	2442767	11.5
140	2442885	6.1	2443052	11.4
141	2443171	6.5	2443333	11.1
142	2443451	6.0	2443621	11.0
143	2443740	6.1	2443916	----
144	2444022	6.6	2444174	10.9
145	2444312	6.4	2444467	10.6
146	2444592	5.7		

TABLE II

Unpublished AAVSO Data for R Hydrae

Cycle	JD(Max)	Mag.(Max)	JD(Min)	Mag.(Min)
223	2433070	5.6	2433271	9.3
224	2433471	5.2	2433650	9.0
225	2433850	5.0	2434032	9.1
226	2434235	4.8	2434415	9.2
227	2434630	4.6	2434816	9.3
228	2435000	4.8	2435193	9.4
229	2435394	5.4	2435586	9.2
230	2435780	5.3	2435972	9.3
231	2436165	4.9	2436365	9.2
232	2436570	4.9	2436765	9.1
233	2436963	4.7	2437161	9.4
234	2437370	4.8	2437570	9.3
235	2437756	4.9	2437950	9.0
236	2438142	4.8	2438338	9.3
237	2438540	4.9	2438721	9.2
238	2438920	5.2	2439111	9.4
239	2439312	5.0	2439511	8.9
240	2439692	4.8	2439912	9.2
241	2440107	6.0	2440305	8.9
242	2440490	6.0	2440700	9.0
243	2440878	---	2441084	8.9
244	2441270	5.0	2441475	9.2
245	2441670	5.0	2441882	9.2
246	2442075	5.2	2442280	9.0
247	2442454	6.0	2442620	9.0
248	2442828	5.2	2443040	---
249	2443218	5.3		
250	2443599	5.4		
251	2443988	5.3		
252	2444350	5.4		

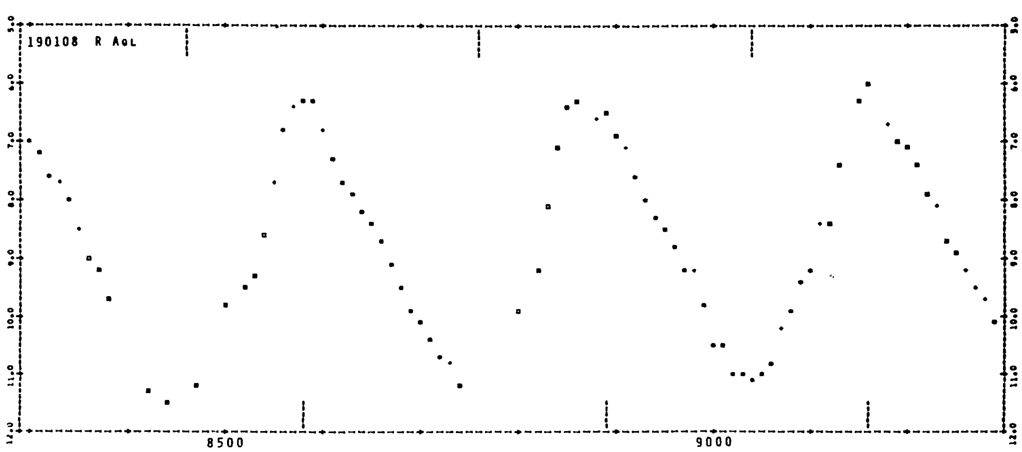


Figure 1. AAVSO light curve of R Aquilae from 1963 to 1966.

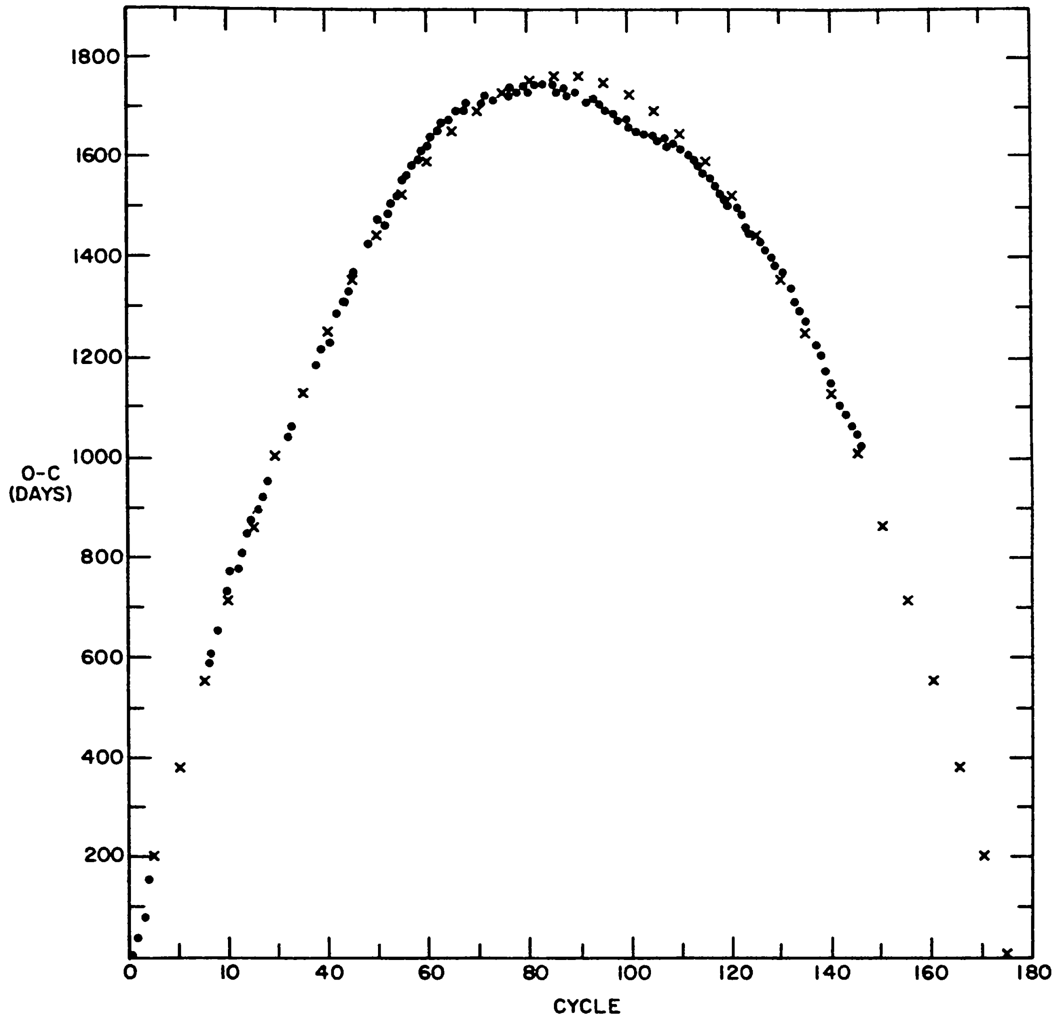


Figure 2. O-C curve for R Aquilae. Dots (•) represent O-C values of the data set. Crosses (×) represent computed values for the fitted parabola.

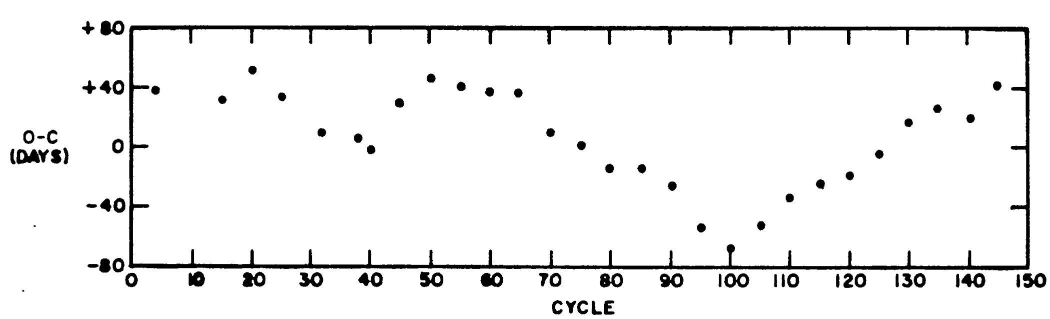


Figure 3. Plot of observed maximum (O) minus ephemeris maximum (C) for R Aquilae.

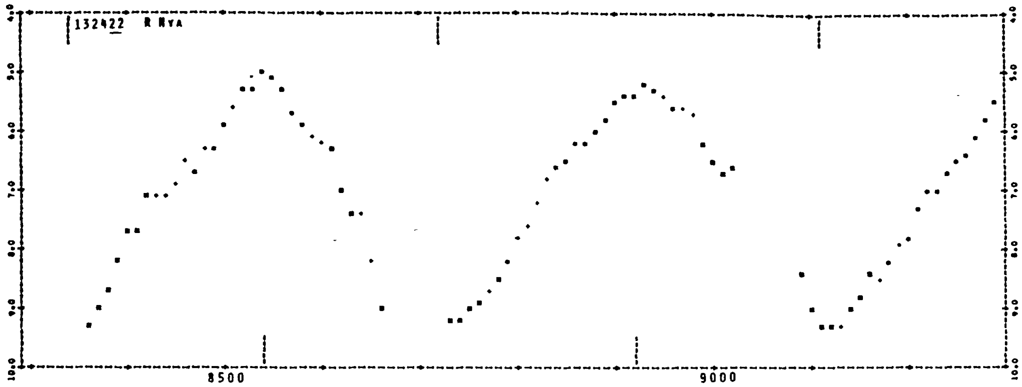
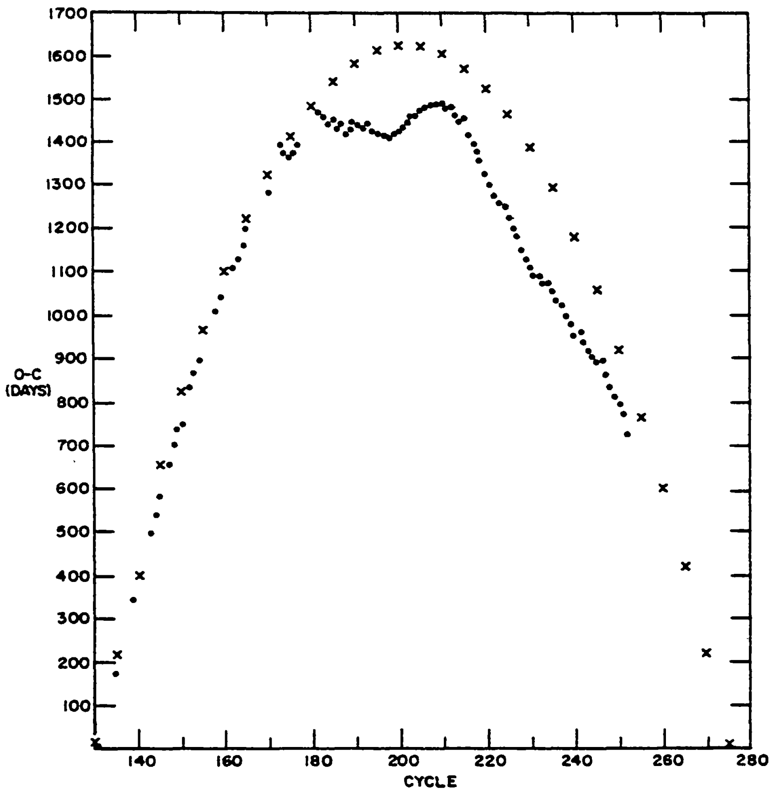


Figure 4. AAVSO light curve of R Hydrae from 1963 to 1966.



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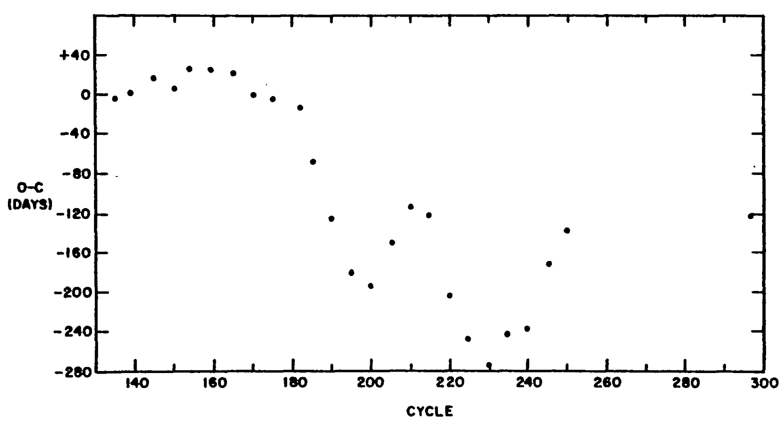

Figure 6. Plot of observed maximum (O) minus ephemeris maximum (C) for R Hydrae.