ANALYSIS OF LONG-TERM AAVSO OBSERVATIONS OF RS OPHIUCHI

Benjamin D. Oppenheimer[1]
Janet A. Mattei
American Association of Variable Star Observers
25 Birch Street
Cambridge, MA 02138

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Abstract

We present here a study of the five reported outbursts of the recurrent nova RS Ophiuchi, together with an analysis of its light variation between outbursts. We find that the shape and decline rates of the outbursts are strikingly similar to each other. We note the possibility of an additional, unreported outburst in 1945, supported by the similarity of its decline to that of other outbursts. Each interval between outbursts shows periodicity within itself; however, there is no periodicity common to all, and the stronger periods range between 892 and 2283 days.

1. Introduction

RS Ophiuchi is a cataclysmic variable of recurrent nova type. It is an interacting binary system consisting of an M red giant and a blue compact companion (Barbon, Mammano, Rosino 1968; Sanduleak and Stephenson 1973). Due to its composite spectrum it has also been classified as a symbiotic star (Barbon *et al.* 1968). Its orbital period has been derived from the radial velocity lines (Dobrzycka and Kenyon 1994) to be 460 days, and its distance has been estimated to be 1.6 kpc (Hjellming *et al.* 1986).

It has had five reported outbursts, in 1898, 1933, 1958, 1967, and 1985. All of the outbursts show very similar light curves.

RS Oph is the only known recurrent nova that shows significant light fluctuations between outbursts. In this study we analyzed the long-term behavior of RS Oph both during outbursts and between outbursts, using mostly AAVSO observations spanning 104 years (Figure 1).

2. Observations and Analysis

RS Oph has been in the AAVSO observing program and well-monitored by hundreds of observers since its 1933 outburst (Figure 1). For this study we have utilized 26,966 visual observations from the AAVSO International Database and Archives between 1920 and May 1993, and 565 photographic observations from Harvard plates from 1890 to 1916 (Campbell 1920). We have studied the outbursts and the intervals between them separately. We used 0.5-day means of the observations for the outbursts and 1-day means for the non-outburst intervals.

2.1. Outbursts

An outburst of RS Oph is defined as the sudden rise in brightness from quiescent state to about 5th magnitude within 24 hours. Each outburst was studied individually, and then superimposed onto each other. Three stages of decline were found from

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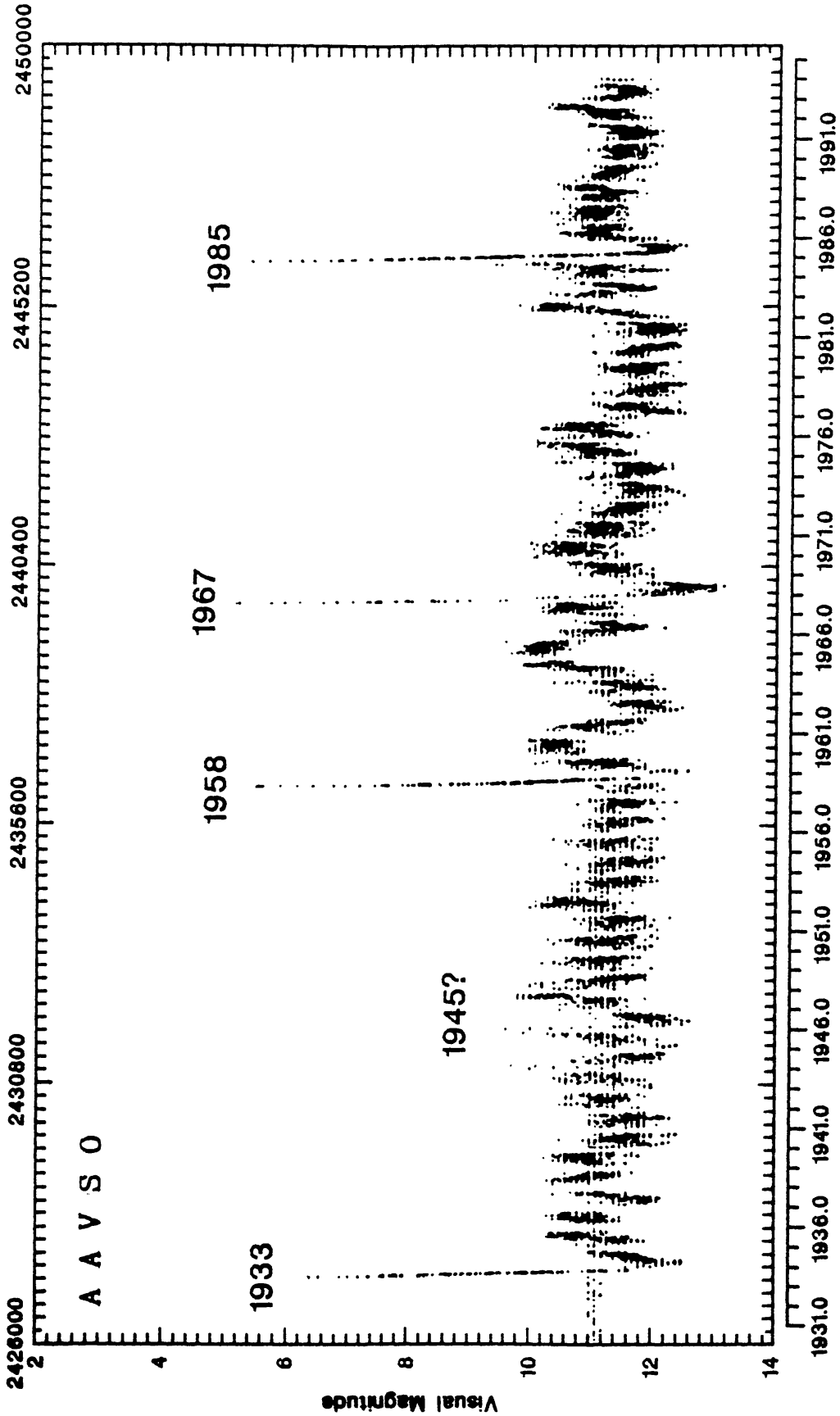
Figure 1. Light curve of AAVSO observations of RS Ophiuchi from 1930 to mid-1993, plotted date (top—Julian Day, bottom—year) vs. visual magnitude.

maximum to minimum. Each of these stages was isolated and decline rates obtained for each. Particular attention was given to the interval following an observing gap, beginning in December 1945, when the star was observed to be bright at magnitude 9.6. This interval was studied thoroughly and the decline rate of the light curve was compared with the rest of the outbursts to check whether this was an unreported outburst caught at the tail-end.

2.2. Intervals between outbursts

Six intervals between outbursts from 1898 to 1993 were identified and each interval was analyzed using the Date-Compensated Discrete Fourier (DCDF) analysis technique (Ferraz-Mello 1981) developed for MS-DOS at the AAVSO. For each interval, a primary Fourier transform was taken, followed by a residual and a second residual, to find the possible strong periods. Particular attention was given in search of both the 230-day period and the 460-day spectroscopic orbital periods reported by Garcia (1986), then later revised by Dobrzycka and Kenyon (1994).

3. Discussion

3.1. Outbursts

Each of the five reported outbursts is strikingly similar to the others. In each outburst, the rise to maximum is fast, as the star brightens by about 6 magnitudes within 24 hours, reaching maximum visual magnitude of about 5.5; the star then immediately starts to fade. The decline from an outburst is in three stages. The first stage is the fastest, averaging 0.09 mag/day and lasting 43 days, followed by a decline rate of only 0.02 mag/day until 85 days after outburst. The average rate of decline of the final stage is 0.05 mag/day, lasting until 122 days after outburst (see Table 1).

Table 1. Outbursts of RS Ophiuchi

Outburst Year	JD Max (2400000+)	Max mag	$\Delta t(1)$ (days)	Rate of $\Delta t(1)$ (mag/d)	$\Delta t(2)$ (days)	Rate of $\Delta t(2)$ (mag/d)	$\Delta t(3)$ (days)	Rate of $\Delta t(3)$ (mag/d)
1898	14442?	—	51	0.06?	112	0.01?	128	0.06?
1933	27297	6.4?	48	0.06?	81	0.02	118	0.06?
1945?	31786?	—	—	—	76	—	118	0.05?
1958	36399	5.4	41	0.10	89	0.02	117	0.04
1967	39791	4.9	39	0.12?	89	0.02?	140	0.04
1985	46094	5.4	38	0.10	65	0.02	111	0.05
Average		5.5	43	0.09	85	0.02	122	0.05

During the secondary decline phase, the star brightens slightly and the decline rate slows down. This interval coincides with the appearance of the forbidden coronal lines of [Fe X], [Fe XIV], and [A X]; the forbidden lines of [O III] and [N II]; and permitted lines of N III, He I, and He II in the spectrum of each outburst (Barbon, Mammano, Rosino 1968; Hack and Selvelli 1993). The appearance of some of the coronal lines in the visual spectra, such as [Fe X] and [Fe XIV], may cause the overall visual brightness to increase. As they weaken, the star fades and continues to decline at the third, faster rate.

The star reaches minimum at about magnitude 12.5, on the average 216 days after outburst. It then brightens, reaching a mean maximum of magnitude 10.3 in 501 days, or 717 days after outburst maximum.

3.1.1. Outburst in 1945

There is strong evidence in the AAVSO observations that RS Oph had another outburst in December 1945 (JD 2431786), which has not been reported previously. An observation made at magnitude 9.9 on JD 2431784, 2 days before the possible maximum outburst, may have been the beginning of the rise to maximum. For the next 68 days, the star was in its seasonal observing gap. On JD 2431854, 65 days after the possible maximum, it was observed at magnitude 9.6. Over the next 69 days, the brightness fell 2.9 magnitudes, a rate of change never before observed in this star for such an extended amount of time outside outbursts. The light curve and the rate of decline are similar to the third stage of other outbursts. After reaching minimum the star brightened by 2.5 magnitudes in 521 days, a behavior also seen in other outbursts. Thus, we strongly believe that RS Oph indeed had another outburst in 1945 which has not been reported or published until now. The occurrence of this outburst may have bearing on the modeling of the system in that with the 5 known outbursts, the average interval between outbursts is 22 years, whereas with an outburst in 1945, the average reduces to 13 years between the 1933 and 1985 outbursts. With so few observations between 1898 and 1933, one or more outbursts could have been missed, thus this interval has not been included in the averages.

3.2. Intervals between outbursts

The light curve outside of the outbursts resembles the light curves of other symbiotic stars such as Z And and CH Cyg. These stars show significant oscillations with multiple periods.

The intervals between outbursts of RS Oph vary from each other both in the amplitude of variation, ranging between one and three magnitudes, and in the complexity of the modulations. The AAVSO light curve from 1930 to May 1993 (Figure 1) shows the long-term behavior and the activity between outbursts clearly. The intervals between the 1958–1967 and the 1967–1985 outbursts appear to be more active, showing the largest range of variation.

After the decline of each outburst, there is a secondary brightening, reaching a minor-maximum up to magnitude 9.6 on the average of 717 days after the outburst. This is usually followed by two or three similar modulations until the next outburst.

The Date-Compensated Discrete Fourier Transform (DCDFT) applied to each of the intervals indicates that there is no common period between these intervals. Modulations between outbursts are multiperiodic, with the possible stronger periods ranging from 892 to 2283 days. The whole data set, excluding the outbursts, was also studied, and the DCDFT applied to this set indicates a period of 2016 days.

A weak period of 471 days was found for the time interval 1985 to 1993. This period is within the errors of the 460-day orbital period derived by Dobrzycka and Kenyon (1994). The DCDFT found no period at or close to the 260-day orbital period found by Garcia (1986).

Further analysis of the AAVSO light curves is being carried out in search of a 50- to 70-day period reported by Tempesti (1975) in the photoelectric data between 1972 and 1973.

4. Conclusions

The outburst light curves of RS Oph are very similar to each other and show three stages of decline. The first stage is the fastest, the second is slower, and the third is

intermediate in rate of decline. There is minor brightening during the second stage that may coincide with the appearance of coronal lines in the spectra.

The outbursts may be phase-dependent, occurring near the minimum of a modulation and followed by rise to secondary minor-maximum after each outburst. The mechanism causing the modulations, particularly the longer ones, may be connected to the occurrence of the outbursts.

There is strong evidence in the AAVSO data of an unreported outburst in 1945.

RS Oph shows significant fluctuation between outbursts, varying between magnitudes 9.6 and 12.8. The light variation shows a wide variety of behavior from one interval to the next, with no period of variation common to all intervals. The most prominent periods of the intervals range from 892 to 2283 days. The only prominent period for the entire data set was found to be 2016 days.

5. Acknowledgments

References

Barbon, R., Mammano, A., and Rosino, L. 1969, *Non-Periodic Phenomena in Variable Stars*, Ed. L. Detre, Academic Press, Budapest, 527.
Campbell, L. 1920, *Ann. Harvard Coll. Obs.* **81**, No. 5.
Dobrzycka, D., and Kenyon, S. J. 1994, *Astron. J.* **108**, 2259.
Ferraz-Mello, S. 1981, *Astron. J.* **86**, 619.
Garcia, M.R. 1986, *Astron. J.* **91**, 1400.
Hack, M., and Selvelli, P.L. 1993, *Cataclysmic Variables and Related Objects*, Ed. M. Hack and C. la Dous, NASA SP-507, Washington, D.C., 511.
Hjellming, R.M., van Gorkom, J.H., Taylor, A.R., Seaquist, E.R., Padin, S., Davis, R.J., and Bode, M.F. 1986, *Astrophys. J.* **305**, L71.
Pottasch, S.R. 1967, *Bull. Astron. Inst. Netherlands* **19**, 227.
Sanduleak, N. and Stephenson, C.B. 1973, *Astrophys. J.* **185**, 899.
Tempesti, P. 1975, *Inf. Bull. Var. Stars*, 974.