FAST VARIATIONS OF THE MEAN BRIGHTNESS AND OTHER LIGHT CURVE PARAMETERS OF THE CARBON MIRA-TYPE STAR S CEP

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Submitted December 31, 1998

Abstract

The variability of S Cephei was studied by using amateur observations from the AFOEV and VSOLJ databases. Fast variations of mean brightness and minimum magnitude with a cycle of 1500 days has been found. Correlation analysis of the individual cycle characteristics has been performed. The hump in the ascending branch and its influence on the light curve are analyzed. The relations between the individual cycle characteristics are discussed.

1. Introduction

The Mira-type star S Cephei is among the intensely studied carbon Miras. The *General Catalogue of Variable Stars* (GCVS) (Kholopov *et al.* 1985) lists its period P = 486.84 days, asymmetry M–m = 0.55, range of brightness variation visual magnitude 7.4–12.9, and a spectrum of C7.4e (N8e). Similar to many carbon stars, it has an unstable light curve, in which a hump or a double maximum sometimes appears. Papers which discuss the masses, velocities, infrared and spectral observations, and other questions concerning carbon stars, including S Cep, include Barnbaum (1992), Hinkle and Barnbaum (1996), Chan (1993), Sloan *et al.* (1998), etc. The variations of the light curve characteristics of S Cep were studied by Isles and Saw (1989) and Mattei and Foster (1998). Isles and Saw (1989) noted the presence of a correlation between magnitudes at different points in the cycle and variations of the mean brightness with a cycle length of about 6000 to 9000 days.

In this paper we have used 4257 amateur observations from the AFOEV (Association Française des Observateurs d'Étoiles Variables) and VSOLJ (Variable Star Observers League of Japan) databases to trace the light curve variations and their interrelations during a 77-year (28000-day) interval.

2. Methods

We have used a trigonometric polynomial fit (Andronov 1994) to obtain the mean phase light curve. The statistically significant degree of the polynomial was determined by using Fisher's criterion. The "running parabola" (RP) fit (Andronov 1997) was used for the determination of characteristics of individual cycle extrema.

Correlation analysis of individual cycle characteristics, similar to that described by Andronov and Marsakova (1998), has been performed. A correlation was accepted as significant if

$$\frac{\rho}{\sqrt{(1-r^2)/(n-2)}} > 3\,, \qquad (1)$$

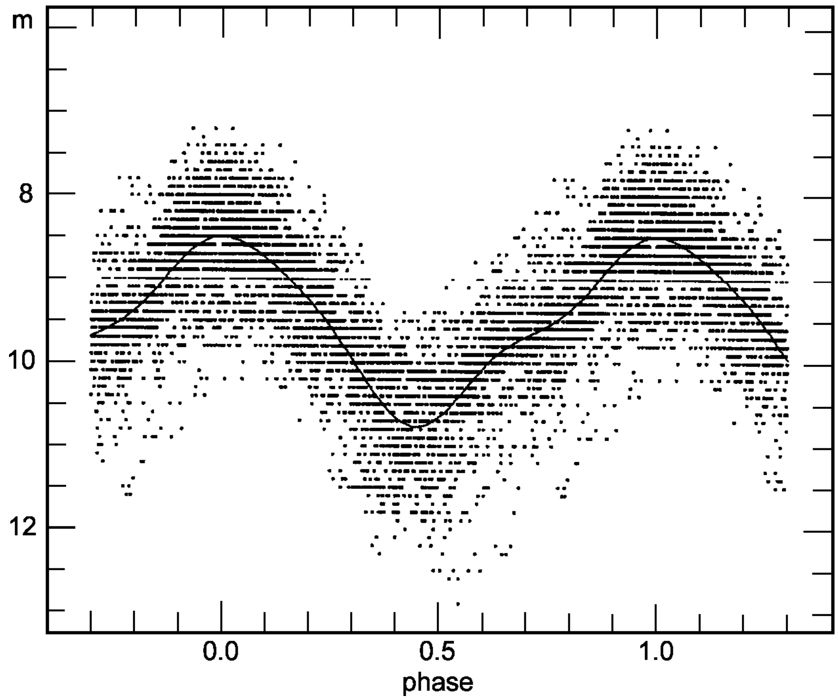

Figure 1. Mean phase light curve of S Cep fitted by a 3-d order trigonometrical polynomial.

where ρ – the correlation constant $\sqrt{(1-r^2)/(n-2)} = \sigma_\rho$ (e.g., Korn and Korn 1961).

3. Variation of the light curve characteristics

The mean characteristics obtained by a trigonometrical polynomial of 3-d degree (Figure 1) differ a little from the ones listed in the GCVS:

period (days)	487.34 ± 0.04
epoch (days)	2438430 ± 2
asymmetry	0.552 ± 0.005
amplitude (magnitude)	2.28 ± 0.02
range (magnitude)	7.2–12.9

Variations of some individual cycle characteristics are shown in Figure 2.

Most clear are the variations of mean brightness calculated as an average between the magnitudes of minimum and maximum and corresponding to the middle time of the ascending or descending branch. The variations are quasi-periodic: they increase and decrease alternately with no fixed cycle length. The curve is broken only near JD 2425000–2429000, where the light curve is most unstable (see Figure 3). The cycle length of mean brightness varies from 1500 to about 3500 days. However, there are gaps in the middle of the observational interval and some cycles are lost, so the 6000-day value given by Isles and Saw (1989) may be an upper limit of the cycle length.

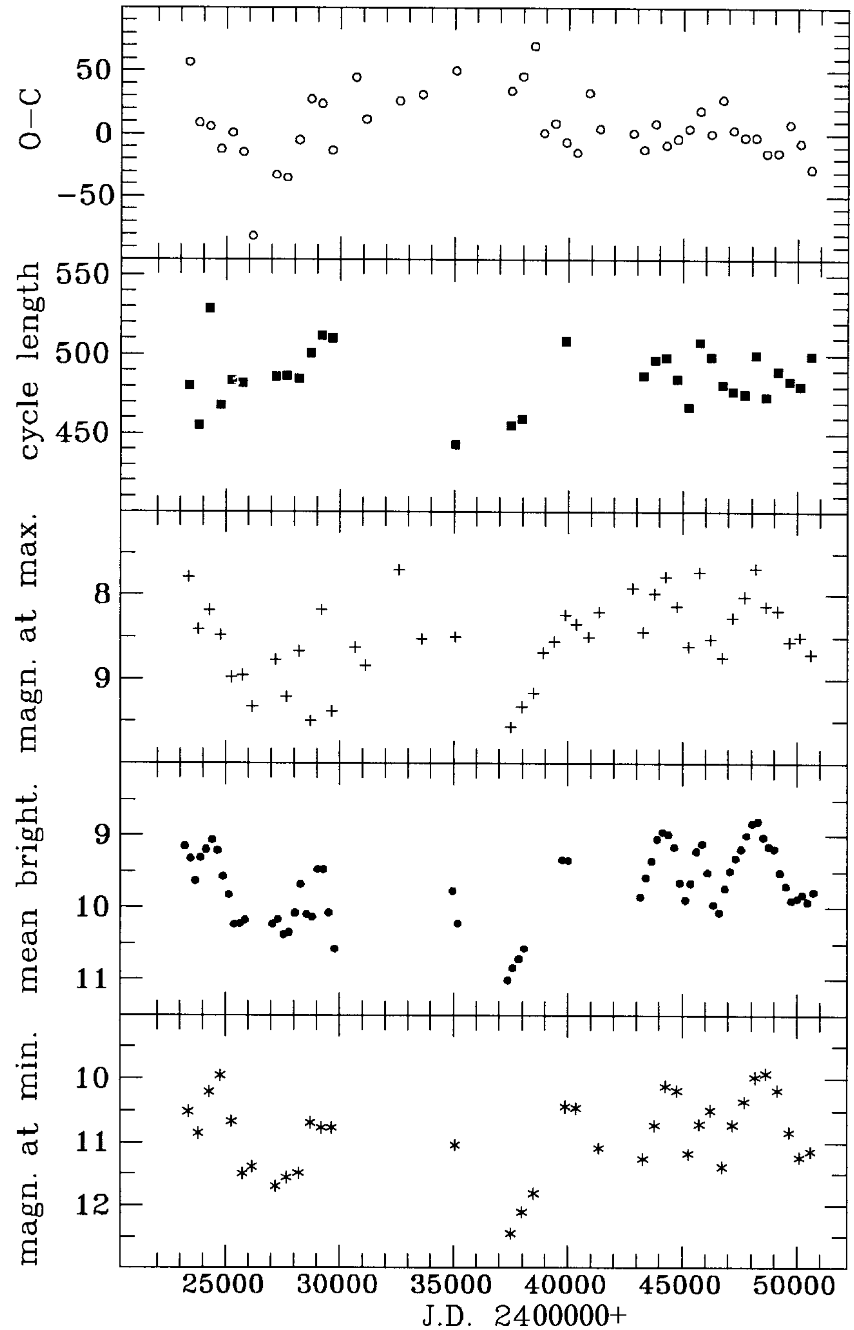

Figure 2. Variations of the individual cycle characteristics for S Cep: O–C, cycle length, magnitude at maximum, mean magnitude, magnitude at minimum.

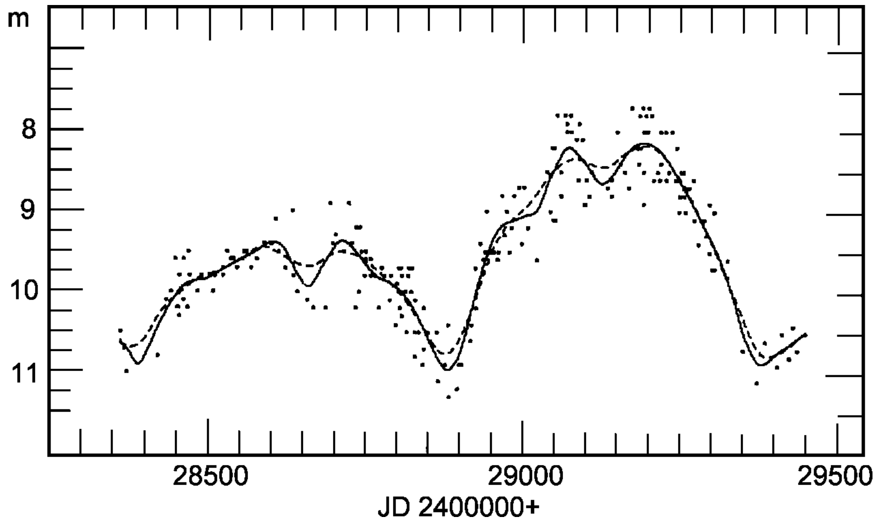

Figure 3. Part of the light curve of S Cep where it is most unstable. Solid and dashed lines correspond to RP fits with Δt = 100 and 200 days, respectively.

Comparison with variations of other characteristics shows that the variations of mean and minimum brightness are most similar.

The correlation coefficient between the amplitudes of minimum and maximum of an individual cycle is equal to $\rho = 0.70$; $\rho/\sigma_\rho = 5.7$, but there is a smaller correlation between the variations of mean brightness and brightness at maxima. The RP fit indicates close values of best-fit filter half-width Δt for the O–C curves and brightness at maximum (6500 days and 6300 days, respectively), but the signal-to-noise ratio for this fit is 2.3, and so we cannot speak with certainty about variations of period and magnitude at maximum.

The cycle length of pulsations shows a large scatter. Figure 2 shows that the period between maxima varies from 418 to 534 days. The period between minima varies from 443 to 529 days, a scatter of 30 days less than for the maxima.

4. Hump in the ascending branch

Altogether 44 maxima were included in this analysis. The hump in the ascending branch was found in 25 cycles. Its shape and location in the curve vary significantly. In Table 1, we show the correlations we have found concerning the hump. It is clear that

Table 1. Correlations concerning the hump in the ascending branch of S Cep.

Parameters	ρ	ρ/σ_ρ
Magnitudes of hump and minimum	0.65	3.9
Magnitudes of hump and maximum	0.55	3.2
Magnitudes of hump and difference between magnitudes of current and previous maximum	0.63	3.6

the magnitude of the hump is better correlated with the magnitude at minimum than with the magnitude at maximum.

The third correlation in Table 1 may be explained by the presence of the second correlation accompanied by a small negative correlation of the hump with the magnitude at previous maximum.

5. Discussion

Thus, we can determine variations of maximum and minimum (mean brightness) of any cycle.

For many Mira-type stars, the minimum seems to be a more stable state than the maximum (see, for example, Mennessier 1985). In our case the minimum state shows: smaller scatter of cycle length, more prominent variations of brightness, more clear relation with hump. Variation of magnitude at minimum and mean brightness during several cycles of mean period seems not to be related to main pulsation period processes.

Variations of brightness at maximum are probably caused both by variations in the main brightness state and the influence of a wave producing a hump. One can suggest that they are also related to cycle-to-cycle period changes.

6. Acknowledgements

The author is thankful to Prof. I. L. Andronov for the computer programs and to all amateurs for their intensive observations.

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