EXAMINATION OF THE COMPLICATED CEPHEID HR 7308

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Abstract

New B and V observations of the variable-amplitude classical Cepheid HR 7308 are used to determine whether the change in amplitude is periodic. It is shown that while the amplitude change is not simply periodic, it may be semiregular, with approximate elements of JD_{max} = 2447410 + 1258 E.

1. Introduction

HR 7308 (HD 180583, V473 Lyrae) has been of interest to variable star researchers since the early 1980's. Originally noted as a semiregular variable by Breger (1969) and then as a periodic variable by Percy *et al.* (1979), its true nature as a periodic variable with changing amplitude only became apparent after several years' worth of data had been accumulated (Burki and Mayor 1980a; Percy and Evans 1980).

HR 7308 appears to be a classical Cepheid lying off the instability strip (Fernie 1982). It has the shortest period known for a classical Cepheid, 1.490808 $\pm$ 0.000010 days (Cabanela 1990), and is the only known example of a classical Cepheid which changes amplitude cyclically (Burki and Mayor 1980b). Several mechanisms for this amplitude change have been proposed (Burki *et al.* 1986), but the beating of closely spaced frequencies appears to have been ruled out (Percy and Ford 1981).

The Fairborn Observatory's Phoenix 10 Telescope, an Automatic Photoelectric Telescope (APT) on Mt. Hopkins (Boyd *et al.* 1986), was used to monitor HR 7308 from early 1987 to late 1988, an interval of about 570 days.

2. Observations

The APT obtained differential magnitudes of HR 7308 with respect to the commonly used comparison star HR 7280 (HD 179422). Between JD 2446905 and JD 2447477, we obtained 88 differential V and 89 differential B observations, which were combined to form a total of 87 B-V measurements. The V observations made by the APT were combined with previous V observations (Percy and Evans 1980; Breger 1981; Burki and Mayor 1980b; Burki *et al.* 1982; Fernie 1982; Henriksson 1983; Burki *et al.* 1986) to study changes in amplitude from early 1966 to late 1988.

3. Analysis

3.1. Light and Color Curves from the APT Data

With a procedure used earlier for examining HR 7308's varying light curves (Cabanela 1990), I divided the data into five time intervals (Table 1) of approximately constant amplitude. The semi-amplitudes and means were calculated as done by Burki *et al.* (1986), using least-squares fits of the V and B to a Fourier series. The period was fixed at 1.490808 days (Cabanela 1990). Satisfactory fits were found with one sinusoid for the first three time intervals and two sinusoids for the fourth and fifth time intervals (the highest amplitudes).

Table 1. The time intervals used for analyzing the V, B, and B-V curves of HR 7308 and the number of data points in each.

Interval	*JD-2440000*	*Number of Datapoints*		
		delta V	*delta B*	*B-V*
1	6905 - 6985	20	21	19
2	7066 - 7112	12	13	12
3	7242 - 7262	16	15	15
4	7415 - 7445	22	22	22
5	7445 - 7477	18	18	18

To find the B-V color index of HR 7308, each pair of simultaneous (within 0.0001 day) V and B observations from the APT was combined to obtain a differential B-V. Then the B-V of the comparison star, 0.425 (Fernie 1982), was added to obtain the actual B-V. A least squares fit to the B-V data was also calculated for the five separate time intervals of B-V, using the same method described for the V and B curves, except that the fifth time interval required only one sinusoid for an acceptable least squares fit. The parameters of the different Fourier series are listed in Table 2.

The phase shifts of a B-V curve relative to a V curve has been suggested as a method of determining whether the star is a radial pulsator (Balona and Stobie 1980). The results were inconclusive and do not rule out the possibility of non-radial pulsation.

Table 2: The parameters from the least squares fits of the APT data to the Fourier series:

$$f(t) = A_0 + \sum_{K=1}^{n} A_K \cos[2\pi K(t\text{-Epoch})/\text{Period}]$$

during the five time intervals. The epochs are in the form JD-2440000. The period was fixed at 1.490808 days.

Data	A_0	A_1	$Epoch_1$	A_2	$Epoch_2$
V (1)	-0.189±0.002	0.055±0.008	6905.9046		
V (2)	-0.188±0.003	0.089±0.006	7065.4425		
V (3)	-0.171±0.003	0.121±0.006	7241.3575		
V (4)	-0.168±0.002	0.174±0.005	7414.3067	0.052±0.008	7415.6802
V (5)	-0.171±0.003	0.163±0.012	7445.5856	0.054±0.012	7446.2651
B (1)	+0.020±0.002	0.087±0.005	6905.8933		
B (2)	+0.015±0.003	0.137±0.006	7065.4099		
B (3)	+0.031±0.003	0.176±0.005	7241.3309		
B (4)	+0.043±0.003	0.259±0.008	7414.2866	0.064±0.008	7415.6860
B (5)	+0.044±0.003	0.242±0.012	7445.5786	0.065±0.012	7446.2592
B-V(1)	+0.634±0.002	0.031±0.005	6905.8835		
B-V(2)	+0.633±0.003	0.040±0.006	7065.3492		
B-V(3)	+0.626±0.003	0.057±0.005	7241.2717		
B-V(4)	+0.636±0.002	0.087±0.008	7415.7366	0.021±0.008	7415.6980
B-V(5)	+0.640±0.002	0.070±0.005	7445.5728		

3.2. Amplitude Variations

Several papers have suggested that the amplitude variations of HR 7308 are periodic, with suggested periods ranging from 955 days (Percy and Evans 1980) which Percy and Ford (1981) rejected, to 1400 days (Burki *et al.* 1986). The APT observations were combined with previously published V data to obtain an extended data set, using a computer program written for this purpose.

The procedure adopted for studying the amplitude variation was to divide the data into bins 30 days wide, so that the amplitude and mean could be assumed to be approximately constant within the bin. Within each bin the V light curve was considered to be approximately a cosine curve with period 1.490808 days (Cabanela 1990), epoch of maximum at JD 2439302.795 (Breger 1981), and constant semi-amplitude. The mean magnitude and the semi-amplitude within each bin can be found by least squares solution. A computer program was written to do this for overlapping bins centered at 5-day intervals between JD 2439000 and JD 2447500. It produced semi-amplitudes and means for the light curve whenever there were enough data points, five data points in a bin being considered enough for generating semi-amplitudes and means with reasonable precision. Figure 1 shows the semi-amplitudes as a function of JD.

Two types of period search were used to look for periodicity within the semi-amplitude data created by this procedure. One of the methods used was the Date Compensated Discrete Fourier Transform (DCDFT) (Ferraz-Mello 1981) but it was considered only an estimate since the semi-amplitude curve, Figure 1, is clearly not sinusoidal and a Fourier Transform calculates the best fitting sinusoid. A second method used was Stellingwerf's (1978) phase dispersion minimization (PDM) method. PDM makes no assumption as to the shape of the curve, and hence is useful even for a non-sinusoidal semi-amplitude curve. Table 3 shows the results of these searches for the period of amplitude-variation.

Table 3: Results of searches for the period of the amplitude variations in HR 7308.

Method	*Periods*
DCDFT (Ferraz-Mello 1981)	1263^d
	2414^d
PDM (Stellingwerf 1978)	2467^d
	1258^d

The strongest period found by the PDM method was 2467 days. If semi-amplitude is plotted against phase using this proposed period, however, two peaks are observed. The next most likely possible period found by the PDM method, 1258 days, is about half as long. This suggests that the other period might be simply a multiple of the true period; the PDM method can accept a curve with two maxima because it allows the curve to have any shape. Since the DCDFT method had found a period of 1263 days, this second possible period was supported. Figure 2 is a plot of semi-amplitude against phase, with the phase calculated using a period of 1258 days and an epoch of minimum amplitude at JD 2444000 (Burki and Mayor 1980a).

At first glance, Figure 2 seems to indicate a simple periodicity, but this is revealed as an illusion if one considers a few facts about the graph:

1. There is considerable scatter in phase for a particular semi-amplitude, especially when one considers that scatter of 0.05 in phase corresponds to 63 days.
2. Most of the ascending branch semi-amplitudes come from two 1258-day time

intervals (cycles), JD 2444000 to JD 2445258 and JD 2446516 to JD 2447774. Also, most of the descending branch amplitudes also come from JD 2446516 to JD 2447774. We can see this in Figure 3, where the semi-amplitudes from those two time intervals have been removed.

3. Lastly, there is what appears to be a late descending branch at about phase 0.95, about 125 days later than expected, which comes from data around JD 24442700. Unfortunately, there are no observations of the corresponding maximum (during that cycle) to confirm this as descending branch data.

These three details confirm the earlier suggestion (Cabanela 1990) that the amplitude variations of HR 7308 are not perfectly periodic. They can be described as semiregular, that is, the amplitude variation completes a cycle about every 1258 days, with the actual period being different every cycle. If we assume that the semiregular interpretation is correct, the elements for HR 7308's amplitude variation are:

$$JD_{max} = 2447410 + 1258\,E, \qquad (1)$$

where the JD for maximum amplitude is taken from APT observations of the most recent maximum. It should be noted that the amplitude at maximum seems to change from cycle to cycle, but it always seems to be at least a factor of seven greater than the minimum amplitudes, which stay fairly constant.

4. Summary

Using APT observations and previously published observations, the amplitude change of HR 7308 is shown to be most likely not a perfectly periodic phenomenon. While only the cyclical nature of the amplitude variations can be demonstrated, it is suggested that they can be considered semiregular with a characteristic time scale of 1258 days.

Future work on this star should include improvement of the amplitude-calculation routine to take into account the non-sinusoidal aspects of the high-amplitude light curves. Also, O-C analysis should look for a possible relation between O-C and amplitude. More photometry needs to be done on this star to determine whether the amplitude change does approximately fit the proposed period of 1258 days or if this was only a temporary period. According to the elements in equation (1), the next amplitude maximum is predicted for February 1992. It may be possible that the amplitude at maximum is related to the rise time. Only future observations of this star can show what is happening.

5. Acknowledgements

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References

Balona, L. A., and Stobie, R. S. 1980, *Mon. Not. Roy. Astron. Soc.*, **190**, 931.
Belserene, E. P. 1988, *J. Amer. Assoc. Var. Star Obs.*, **17**, 123.
Boyd, L. J., Genet, R. M., and Hall, D. S. 1986, *Publ. Astron. Soc. Pacific*, **98**, 618.
Breger, M. 1969, *Astrophys. J. Suppl.*, **19**, 79.
Breger, M. 1981, *Astrophys. J.*, **249**, 666.

Burki, G., and Mayor, M. 1980a, *Inform. Bull. Var. Stars,* No. 1728.
Burki, G., and Mayor, M. 1980b, *Astron. Astrophys.,* **91**, 115.
Burki, G., Mayor, M., and Benz, W. 1982, *Astron. Astrophys.,* **109**, 258.
Burki, G., Schmidt, E. G., Arellano Ferro, A., Fernie, J. D., Sasselov, D., Simon, N. R., Percy, J. R., and Szabados, L. 1986, *Astron. Astrophys.,* **168** 138.
Cabanela, J. E. 1992, *Robotic Observatories: Proceedings of the 1990 Meeting of the Astron. Soc. Pacific,* eds. S. Baliunas, J. Richard.
Fernie, J. D. 1982, *Publ. Astron. Soc. Pacific,* **94**, 537.
Ferraz-Mello, S. 1981, *Astron. J.,* **86**, 619.
Henriksson, G. 1983, *Uppsala Astron. Obs. Rep.,* **26**, 1.
Percy, J. R. 1990, private communication.
Percy, J. R., and Evans, N. R. 1980, *Astron. J.,* **85**, 1509.
Percy, J. R., and Ford, R. P. 1981, *J. Amer. Assoc. Var. Star Obs.,* **10**, 53.
Percy, J. R., Baskerville, I., and Trevorrow, D. W. 1979, *Publ. Astron. Soc. Pacific,* **91**, 368.
Stellingwerf, R. F. 1978, *Astrophys. J.,* **224**, 953.

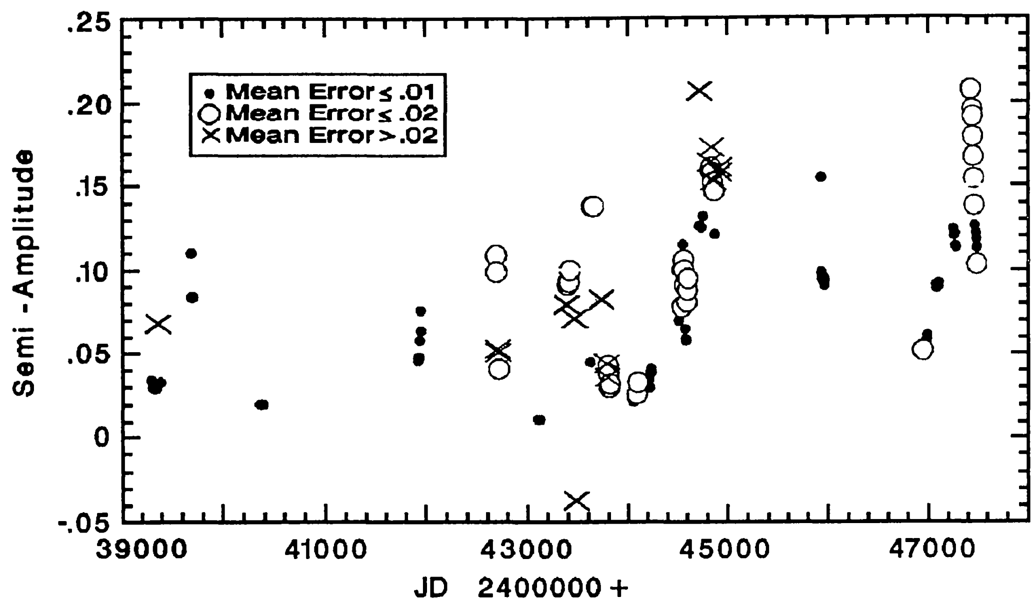

Figure 1. Semi-amplitude in V vs. JD for HR 7308. Computation of the semi-amplitudes is explained in the text. Note: The negative semi-amplitude at JD 2443470 has a mean error of $\pm$0.066.

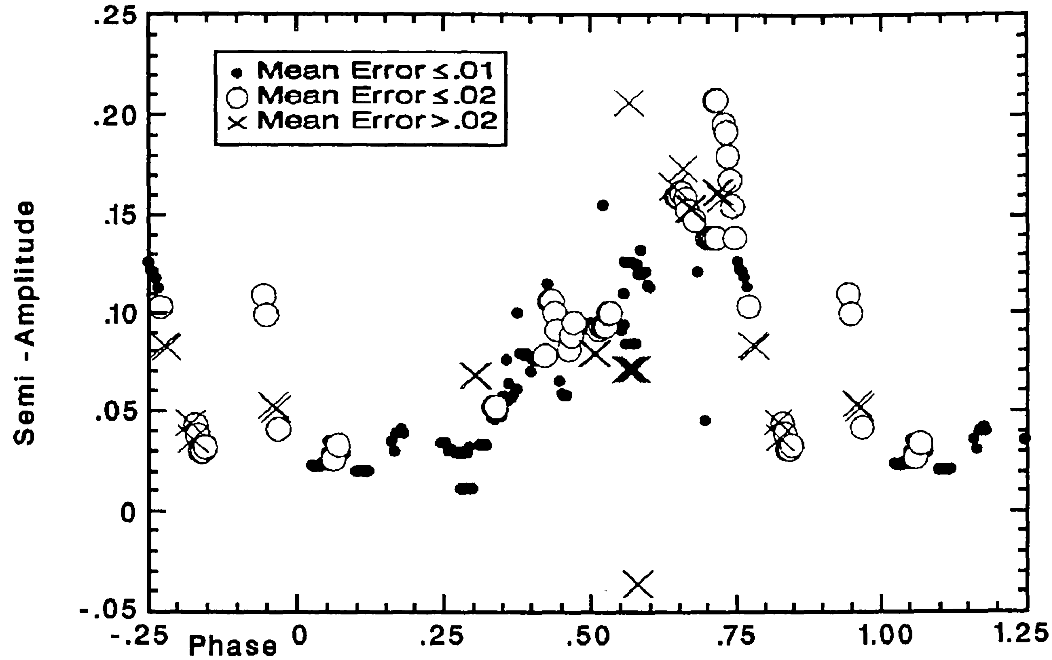

Figure 2. The semi-amplitudes from Figure 1, plotted against phase assuming an epoch at JD 2444000 and a period of 1258 days.

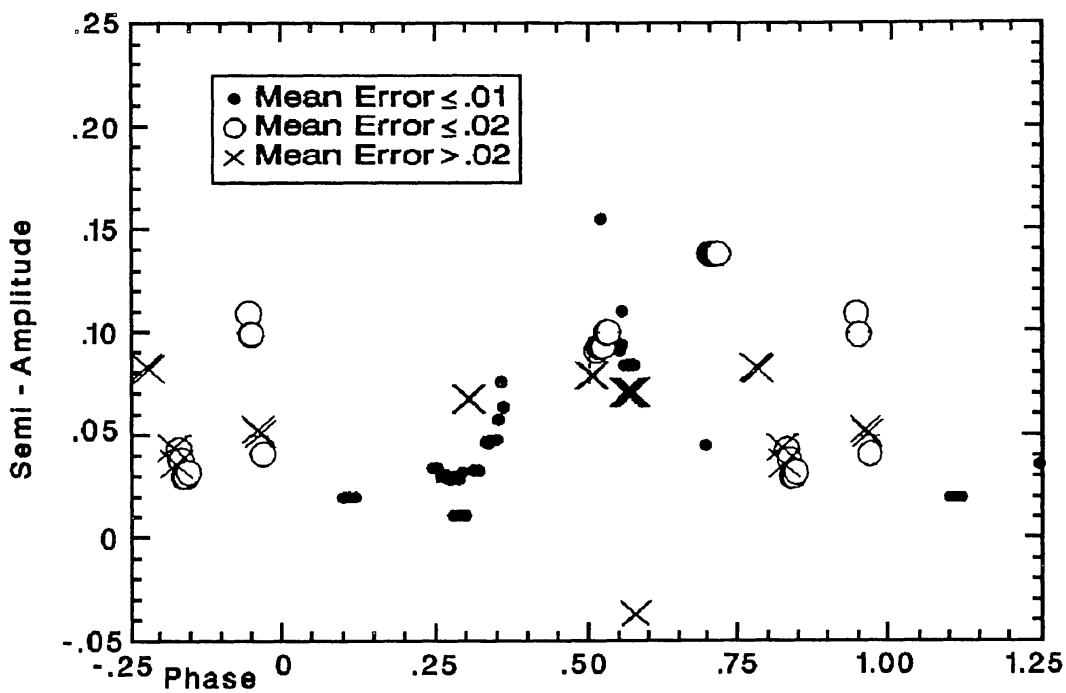

Figure 3. Same as Figure 2 but for a subset of the data. This plot shows that by removing only two cycles' (of 1258 days) worth of semi-amplitude data, periodicity is much more difficult to see.