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A NEW APSIDAL MOTION DETERMINATION FOR DI HERCULIS

DI Herculis (HD 175227) is an 8th magnitude eclipsing binary consisting of two main sequence B stars (B4 V and B5 V) moving in a highly eccentric orbit (e = 0.49) with a period of approximately 10.55 days. Rudkjøbing (1959) first called attention to this system as a possible test of general relativity since the relativistic contribution to the total apsidal motion is expected to be greater than that arising from classical (Newtonian) effects. For DI Her, the classical contribution to the apsidal motion rate, which arises from tidal and rotational deformation of the stars, is expected to be $\dot{\omega}_{cl} = 1.93°/100\text{yr} \pm 0.26°/100\text{yr}$ while the theoretically expected general relativistic contribution is $\dot{\omega}_{gr} = 2.34°/100\text{yr} \pm 0.15°/100\text{yr}$ yielding a combined predicted value of $\dot{\omega}_{cl+gr} = 4.27°/100\text{yr} \pm 0.30°/100\text{yr}$ (Guinan and Maloney, 1985). The rate of the observered apsidal motion of DI Her is well determined from measurements of the times of primary and secondary eclipse. However, in all studies done so far for DI Her, the results indicate an apsidal advance significantly smaller than predicted from theory. For example, Guinan and Maloney (1985) found a value of $\dot{\omega}_{obs} = 0.65°/100\text{yr} \pm 0.11°/100\text{yr}$ and Reisenberger and Guinan (1989) found $\dot{\omega}_{obs} = 1.00°/100\text{yr} \pm 0.30°/100\text{yr}$. The observations used in these studies span a period of about 84 years and indicate an apsidal motion rate 4–7 times smaller than expected from theory. This discrepancy between the observed and theoretical apsidal motions for this star is very puzzling. One of the possible explanations for the smaller than expected observed apsidal motion in DI Her is the presence of a third body which would perturb the orbit of the close eclipsing pair (see Guinan and Maloney 1985, Reisenberger and Guinan 1989, and Khaliullin, Khodykin, and Zakharov 1991).

We have continued to observe DI Her extending the observational baseline to provide a more accurate determination of the rate of apsidal motion and also to search for evidence of small period oscillations due to the presence of a possible third body. Here we report on three new times of minimum light obtained by us using a 0.8m Automatic Photoelectric Telescope (APT); these data are combined with all the previous photoelectric timings to search for evidence of a third body and to refine the determination of the apsidal motion.

Photoelectric photometry was carried out during the spring of 1993 and 1994 resulting in three new timings of minimum light — a secondary eclipse on June 13, 1993 UT, and two primary eclipses on June 26, 1993 UT and May 19, 1994 UT. Observations were made using the Fairborn-Villanova 0.8m APT on Mt. Hopkins, Arizona; observations were taken in Johnson U, B, and V filters. Differential magnitudes were computed in the sense variable minus comparison (V-C) where HD 174932 (V=+8.9; B9) served as the comparison star while HD 343238 (V=+9.7; A2) served as the check star. Extinction corrections were applied using atmospheric extinction coefficients determined from observations of the comparison star, and local standard times were converted into heliocentric Julian days (HJD). The data were reduced using software developed at Villanova University by G.P. McCook. The details of the reduction procedure have been described

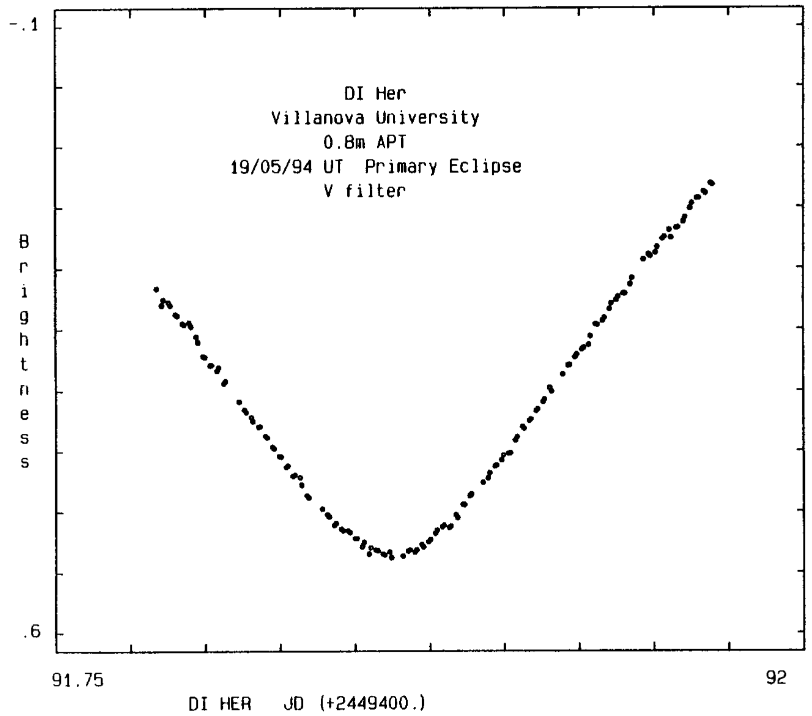

Figure 1. A plot of the differential V-magnitudes obtained during primary eclipse of DI Her on 19 May 1994 UT.

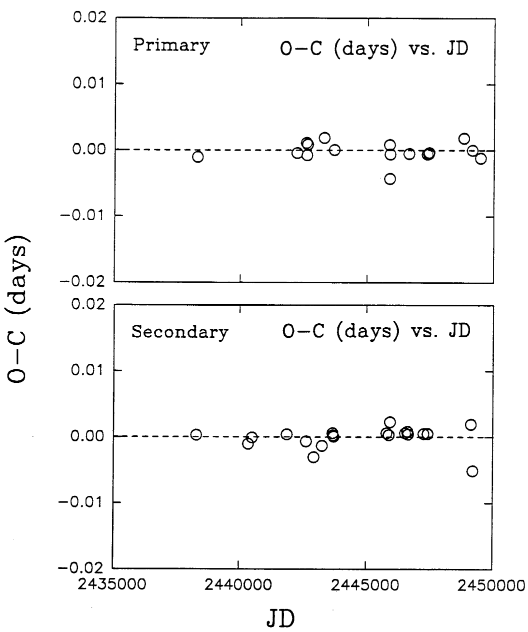

Figure 2. The plots of the (O-C) values versus Julian Date for the photoelectric times of primary and secondary eclipses. The (O-C)s were computedfrom equations (1) and (2) and show no evidence of significant systematic variations expected to arise from a third body.

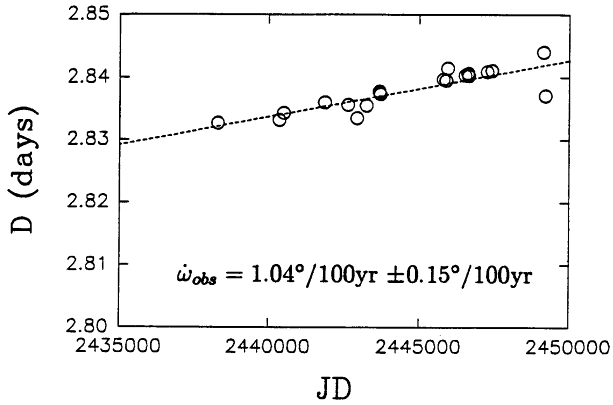

Figure 3. Plot of the displacement of the secondary minimum from a half period point of DI Her, in days, (D=($t_1 + t_2 - 0.5P$)), versus Julaian Date number.

elsewhere by Guinan *et al.* (1987). The differential V-magnitudes of the primary eclipse observed on 19 May 1994 UT are shown in Figure 1.

The times of minimum light were initially determined by a computerized version of the familiar "tracing-paper" method. The reduced data are plotted on the screen as observed and then plotted again with the time axis reversed. The second curve is then positioned so that the two curves appear superimposed and the time of minimum then appears at the same point on both curves. We then formally applied a second order (parabolic) and fourth order least squares fit on the data for the eclipses. The agreements between the times given by the computerized "tracing-paper" method and the least squares fits are very good. The best fits were obtained using the fourth order calculations. Because of the large number of data points (about 200 per night per filter) and good distribution through the minimum, we have obtained very precise determinations of the eclipse timings. The final times of minimum light were obtained by determining the time of minimum independently in the B and V filters, performing the fourth order least squares fit, and averaging the two results. We did not use the U band observations in these determinations because they were noisier than the B and V band data. Our three new times of minima and their corresponding (O-C) values determined using the ephemeris given by Reisenberger and Guinan (1989) are:

T (min II)	=	HJD 2449151.8260 ±0.0005	(O-C)	=	+0.0015	day
T (min I)	=	HJD 2449164.8082 ±0.0002	(O-C)	=	−0.0005	day
T (min I)	=	HJD 2449491.8622 ±0.0002	(O-C)	=	−0.0017	day

It should be noted that the higher observational error indicated for the secondary minimum results, in part, because the lowest portion of the minimum was not covered. As a result of this, this timing should be given a somewhat lower weight.

These eclipse timings and those given by Khodykin and Volkov (1989), Caton and Burns (1993), and Lacy and Fox (1994) were combined with only the more accurate photoelectric timings that have been tabulated by Guinan and Maloney (1985) and Reisenberger and Guinan (1989). Linear least squares fits were made independently to the primary and secondary eclipse data and the following light elements were determined:

T (min I)	=	HJD 2442233.3480 + 10.55016766	(1)
T (min II)	=	HJD 2442241.4600 + 10.55017413	(2)

In Figure 2, we have plotted the (O-C)s found from these fits for both primary and secondary eclipses. This figure includes data from 1963 to 1994. As shown in these plots, there is no evidence of any systematic or periodic variations in the (O-C)s to a level of about ±0.001 days that would suggest the light time effect from a putative third body. These data do not rule out the possibility of a companion, but certainly do not lend any support to this hypothesis. It should also be noted that there is no significant change (to within ±0.01 mag) in the observed eclipse depth compared to previous photoelectric photometry. This indicates that the orbital inclination has been constant to within about ±0.006° and therefore there is no observed evidence for perturbations from a third body.

Following the procedure described by Guinan and Maloney (1985), an apsidal motion rate of $\dot{\omega}_{obs} = 1.04°/100\mathrm{yr} \pm 0.15°/100\mathrm{yr}$ was determined from the change with time of the displacement of the secondary minimum from the half period point. Figure 3 shows the change in the displacement of the secondary minimum, D = $(t_1 + t_2 - 0.5P)$ with time where t_1 and t_2 are the times of primary and secondary eclipse, respectively. The apsidal motion rate found here is essentially the same rate as found previously by Reisenberger and Guinan (1989) and in close agreement to the values given by Guinan and Maloney (1985) and Khodyin and Volkov (1989).

We plan to continue our study of DI Her and will attempt to obtain more photoelectric timings of primary and secondary eclipses during the next several years to further refine the observed rate of apsidal motion and to continue the search for evidence of a third body.

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