COMMISSIONS 27 AND 42 OF THE IAU
INFORMATION BULLETIN ON VARIABLE STARS
Number 4161

Konkoly Observatory
Budapest
15 February 1995

HU ISSN 0374 – 0676

POSSIBLE LOW AMPLITUDE LIGHT VARIATIONS OF DI Her

The eccentric eclipsing binary DI Herculis (B4 V and B5 V; P = $10^{\rm d}\!.55$; e = 0.49) is an important test case of general relativity for stars composed of non-degenerate matter because it is expected to have a large relativistic contribution to its apsidal motion (Rudjkøbing, 1959; Guinan and Maloney, 1985). DI Her has well determined orbital and physical properties and an accurately measured apsidal motion rate of $\dot\omega_{obs} = 1^\circ\!.04/100$yr $\pm 0^\circ\!.15/100$yr determined from the recent analysis of numerous times of primary and secondary eclipses (Guinan et al., 1994). The most remarkable feature of DI Her is that its observed apsidal motion rate is significantly smaller than that predicted by general relativity and classical effects. The total predicted rate of apsidal motion is $\dot\omega_{gr+cl} = 4^\circ\!.27/100$yr $\pm 0^\circ\!.30/100$yr where the general relativistic term is the major contribution.

We are currently carrying out an intensive study of DI Her to search for the reason(s) for the large discrepancy between the observed and predicted apsidal motion rates. In a previous paper, we have refined the value of the apsidal motion rate and have also searched for evidence of variations in the O−C's of the photoelectric eclipse timings, obtained over the last 30 years, that could arise from the light time effects of a possible third body (Guinan et al., 1994). No evidence of the presence of a third body was uncovered from this analysis.

Another possible solution for the smaller than expected apsidal motion rate is tidal dissipation of the system's angular momentum arising from induced pulsations in the stars as they move in their eccentric orbit (see Papaloizou and Pringle, 1980; Savoniji and Papaloizou, 1983). In this case the discrepancy in apparent apsidal motion is produced by a decrease in the orbital eccentricity as the orbit circularizes. However, as discussed by Guinan and Maloney (1985) the rate of change of the eccentricity needed to explain the observed discrepancy is large ($\dot e \simeq -0^\circ\!.01/100$yr) and the induced pulsations in the stars, if present, must be significant and should be observable. With this in mind, we carried out intensive UBV photoelectric photometry of DI Her using the Fairborn-Villanova 0.8m Automatic Photoelectric Telescope (APT) on Mt. Hopkins, Arizona.

Many eclipse timings have been obtained for DI Her, but there have been few attempts to observe the system for a significant amount of time outside of eclipses. During the springs of 1993 and 1994, DI Her was observed continuously (with comparison and check stars) for up to 4 – 5 hours on several nights outside of eclipses. A description of the equipment, filters, comparison and check stars, and reduction technique is found in Guinan et al. (1994). In Figure 1 we present the U and V light curves obtained during 1993/94. From this figure it is apparent that there are small light variations outside the eclipses on time scales significantly shorter than the 10.55 day orbital period. The variations are largest in the U bandpass and barely noticeable in the V bandpass. In Figure 2 we plot two long runs on an expanded magnitude and time scale to show examples of the light variations in the U bandpass. To search for possible periodicities, all of the data were

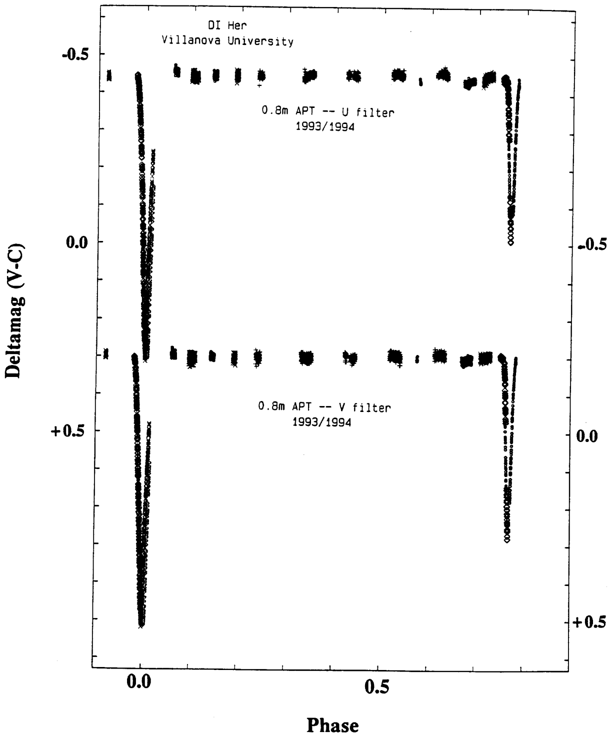

Figure 1. The U and V band light curves of DI Her obtained in 1993/94 are plotted. The magnitudes are differential measured relative to a nearby comparison star HD 174932. Note the small light variations in the U observations outside the eclipses.

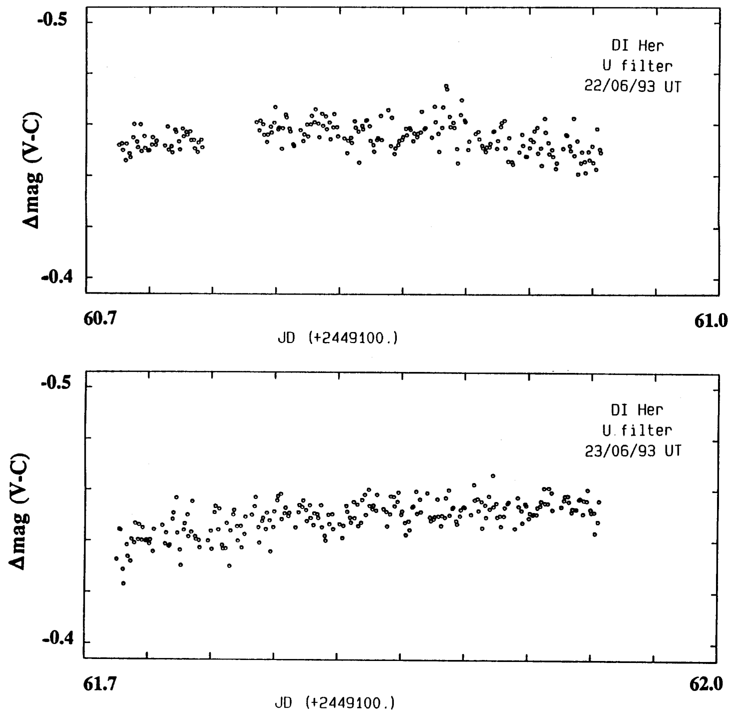

Figure 2. The delta U mags of DI Her for the nights of 21 and 22 June 1993 are shown. Small systematic variations are noticeable on time scales of several hours.

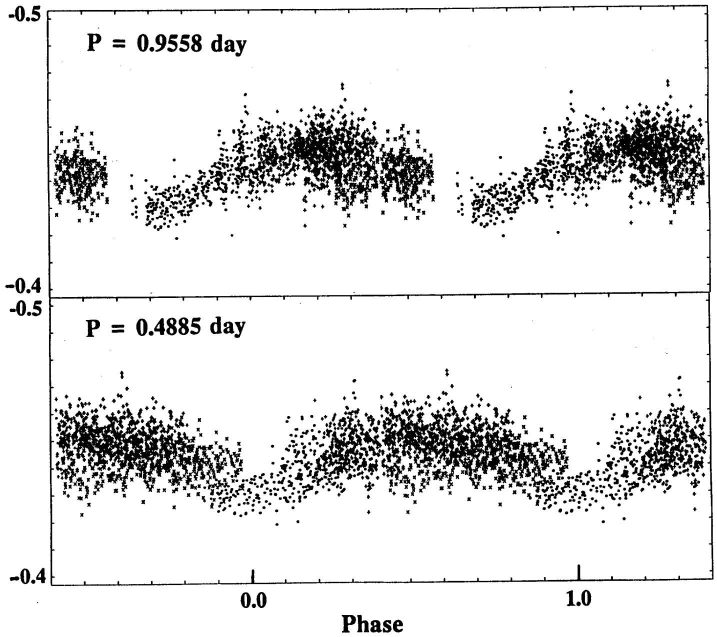

Figure 3. The results of period searches of the U observations outside of eclpises using the Lomb–Scargle method are shown. The two most prominent periods found are 0.4885 days and 0.9558 days and are indicated along with several other possible periods.

analyzed using the Lomb–Scargle algorithm (Press and Teukolsky, 1988).
We narrowed down the possible range of periods to 0.4 to 2.0 days by trial and error and then analyzed the data in this restricted period range. The results are difficult to interpret because there is no single highly prominent peak in the periodogram. This is in most part caused by the low amplitude nature of the light variations (0.01 – 0.02 mag) and gaps in the data set. Our analysis reveals two prominent periods of 0.4885 day and 0.9558 day having relative powers of 201.0 and 197.6 on the periodogram. However, there are other possible periods including 1.2165 days with a lower relative power of 155; it is possible that the 0.4885 day and 0.9558 day periods are aliases of each other. It may also be possible, however, to have multiple periods. In Figure 3, we plot the U light curves computed with the 0.4885 day and 0.9558 day periods, respectively. As shown in the figure, both periods result in a low amplitude sinusoidal light curve. It is difficult to discern which one of the two periods is better. The amplitudes of the U, B, V light variations are 0.020 mag, 0.013 mag, and 0.010 mag, respectively.

We are confident that the light variations discussed above are real. However, there is an uncertainty in the source of the variability because all measurements were made with respect to a nearby comparison star (HD 174932; B9; V=+8.9) which itself could be the source of the observed light variations. Although this is unlikely, we cannot be certain that the comparison is constant in light because the check star (HD 343238; A2; V=+9.7) observations show considerable scatter. The scatter in the check star data is probably due to centering problems with the APT acquiring this faint star (the limiting magnitude for acquisition is +9.6 – +9.7 mag); it is also possible that the check star may be intrinsically variable. We plan further observations next season to resolve this dilemma using additional comparison stars.

The characteristics of the light variations reported here (whether from DI Her or the comparison star HD 174932) are very similar to those found by Waelkens and Rufener

(1985) and Waelkens (1987, 1991) for a proposed new class of stars called slowly pulsating B stars (SPB stars). These stars generally have spectral types ranging from B3 to B8 (with luminosity classes of IV – V) and have light amplitudes of a few thousandths or hundredths of a magnitude that increase with decreasing wavelength; multiple periods are typically seen in the range of about 1.0 – 3.0 days. All the SPB stars seem to show the same dependence of the amplitude on wavelength, with amplitudes in the U bands about twice as large as in the V bands. Furthermore, North and Paltani (1994) have found that the ratio of the amplitude in the (U−B) index and V magnitude is very well correlated with the effective temperatures of the SPB stars. Waelkens (1991) explains the light variations from the SPB stars as arising from non-radial oscillations in the g modes with large radial wave numbers k and low orders l. The ratio of the amplitude of the (U−B) to the amplitude in V for our differential magnitude measures of DI Her is $A_{(U-B)}/A_V = 0.70$. This ratio is similar to that found for SPB stars with spectral types of B4 – B6 which is close the spectral type of the components of DI Her. On the other hand, the comparison star has a spectral type of B9 which is near the observed upper limit for SPB stars. Furthermore, B8 – B9 SPB stars have an amplitude ratio of $A_{(U-B)}/A_V = 0.9 - 1.1$ which is not consistent with our observed value. This evidence lends some support to the hypothesis that the light variations are coming from one or both of DI Her's components and not the comparison star. Observations planned for the future should resolve this issue.

If future photometry confirms that the light arise from DI Her rather than the comparison star, these low amplitude non-radial pulsations would not be sufficient to explain the discrepancy in DI Her's apsidal motion rate from tidal dissipation. It would appear more likely that the light variations may be quite common for stars of their spectral class and is not related to them being members of an eccentric binary system. It is possible that many more B-type stars will show low amplitude light variations and have not yet been discovered because they have not been adequately sampled.

This research was in part supported from NSF grants AST-9315365 and AST-8616362 which we gratefully acknowledge.

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