COMMISSION 27 OF THE I. A. U.
INFORMATION BULLETIN ON VARIABLE STARS
Number 2747

Konkoly Observatory
Budapest
13 June 1985

HU ISSN 0374 - 0676

THE ELLIPTICITY EFFECT AND A MIGRATING WAVE IN THE CHROMOSPHERICALLY ACTIVE TRIPLE SYSTEM V772 Her

V772 Herculis = HD 165590 = ADS 11060 is a triple system very interesting in many respects. Important references are Morbey et al. (1977), Scarfe (1977), Batten et al. (1979), Fekel (1981), Bakos and Tremko (1982), and Stern and Skumanich (1983). From these we get the following picture. A GOV star (the spectroscopic primary) and an M1V star (spectroscopically unseen) orbit each other with a period of $0^d.8795$ at an inclination of $77^o \pm 7^o$. That close pair orbits a G5V star (the spectroscopic secondary) with a period of $20^y.25$ at an inclination of $82^o.7 \pm 2^o.0$. The system is very young, similar in age to the Pleiades, and emits soft x-ray radiation, with $L_x = 4 \times 10^{30}$ ergs/sec. Both the GOV and the G5V stars show Ca II H and K emission in their spectra. The G5V star rotates unusually rapidly (Vsini = 18 ± 2 km/sec) and the GOV star rotates exceedingly rapidly (Vsini = 75 ± 5 km/sec), apparently in synchronism with the short orbital period. The long-period orbit is highly eccentric, with e = 0.958, and last underwent periastron passage in 1978. The short-period orbit undergoes shallow ($\Delta V = 0^m.05$) eclipses and also additional variations outside eclipse which until now have not been understood.

With the 10-inch Newtonian at Fairborn Observatory (Boyd et al. 1984) V772 Her was observed differentially on 21 nights in 1984 in the UBV system, the comparison star being HR 6763 = HD 165524. The data are given in Table I. A preliminary plot, with respect to the ephemeris

$$\text{JD(hel.)} = 2443656.6635 + 0^d.8794998\ n \qquad (1)$$

given by Bakos and Tremko for times of primary eclipse, indicated that V772 Her was in eclipse on two of our 21 nights, marked with a (p) in Table I. They are useful as recent timings of mid eclipse, uncertain by approximately $\pm 0^d.01$. O-C residuals with respect to equation (1) are $+0^d.017$ and $+0^d.003$.

Next we used least squares to fit a sinusoidal light curve to the 19 differential magnitudes outside eclipse, with a range of different periods assumed. The results are shown in Table II, where the second column is the period which gives the smallest variance, the third column is the full amplitude of the wave, and the last column is the Julian date of the minimum of

Table I

Differential Photometry of V772 Her = HD 165590

JD(hel.)	ΔV	ΔB	ΔU	note
2445970.6444	$0\overset{m}{.}903$	$0\overset{m}{.}293$	$-0\overset{m}{.}743$	(p)
2445972.6468	0.812	0.247	-1.054	(f)
2445973.6602	0.843	0.250	-0.920	(f)
2445984.6088	0.860	0.245	-0.793	
2445986.6221	0.854	0.217	-0.857	
2445987.6157	0.824	0.203	-0.847	
2445990.6117	0.870	0.257	-0.779	
2445993.5999	0.842	0.215	-0.841	
2445996.5891	0.886	0.292	-0.720	
2445999.5812	0.837	0.227	-0.810	
2446000.5977	0.832	0.216	-0.831	
2446001.5774	0.812	0.186	-0.875	
2446002.5815	0.877	0.262	-0.790	
2446005.5663	0.838	0.235	-0.811	
2446006.5701	0.857	0.229	-0.819	
2446007.5695	0.909	0.272	-0.799	(p)
2446008.5688	0.836	0.221	-0.839	
2446009.5720	0.867	0.261	-0.768	
2446010.5621	0.883	0.271	-0.773	
2446012.5612	0.849	0.239	-0.825	
2446013.5601	0.853	0.231	-0.849	

Table II

Fourier Analysis of the Migrating Wave

λ	P	Δm	JD(min.)
V	$0\overset{d}{.}8726$ ±.0020	$0\overset{m}{.}0489$ ±.0038	2445970.428 ±.009
B	0.8755 ±.0020	0.0598 ±.0044	2445970.416 ±.008
U	0.8710 ±.0025	0.0965 ±.0064	2445970.420 ±.007

Table III

Fourier Analysis of the Ellipticity Effect

λ	Δm	JD(min.)	O-C
V	$0\overset{m}{.}0136$ ±.0035	2445970.604 ±.010	$-0\overset{d}{.}023$
B	0.0197 ±.0033	2445970.593 ±.005	-0.034
U	0.0469 ±.0052	2445970.617 ±.005	-0.017

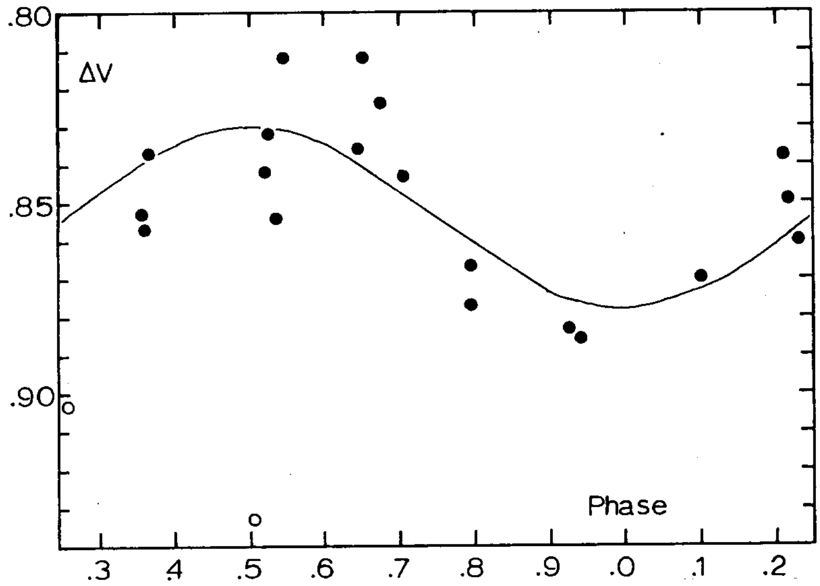

Figure 1

Light curve of V772 Her in V with phase computed from equation (2). The solid curve is a sinusoidal fit of the migrating wave, with zero phase at light minimum. The two eclipse points, open circles, do not coincide here because 0.873 days is not the 0.8795-day orbital period.

the wave. All 21 ΔV values are plotted in Figure 1, where phase is computed with the ephemeris

$$\mathrm{JD(hel.)} = 2445970.421 + 0\overset{d}{.}873\ n, \qquad (2)$$

which is an average of our results in the three bandpasses. The solid curve is a sine wave with a full amplitude of $\Delta V = 0\overset{m}{.}049$ and with its minimum at zero phase. Note that the two eclipse points do not coincide, because $0\overset{d}{.}873$ is not the $0\overset{d}{.}8795$ orbital period.

Our Fourier analysis in the U bandpass omitted values from two consecutive nights, marked (f) in Table I, which gave extremely large residuals, both overluminous. We recall that Bakos and Tremko saw a flare on June 16, 1979 which made the system brighten by $0\overset{m}{.}125$ in U.

In short-period (therefore, presumably, close) eclipsing systems one anticipates a detectable ellipticity effect. Therefore we removed the wave from our observations, using its $0\overset{d}{.}873$ period and the appropriate amplitude for each bandpass, and did another Fourier analysis which allowed for a cos 2θ variation, this time computing phase with the $0\overset{d}{.}8795$ orbital period. Results are shown in Table III, where Δm is the full amplitude of

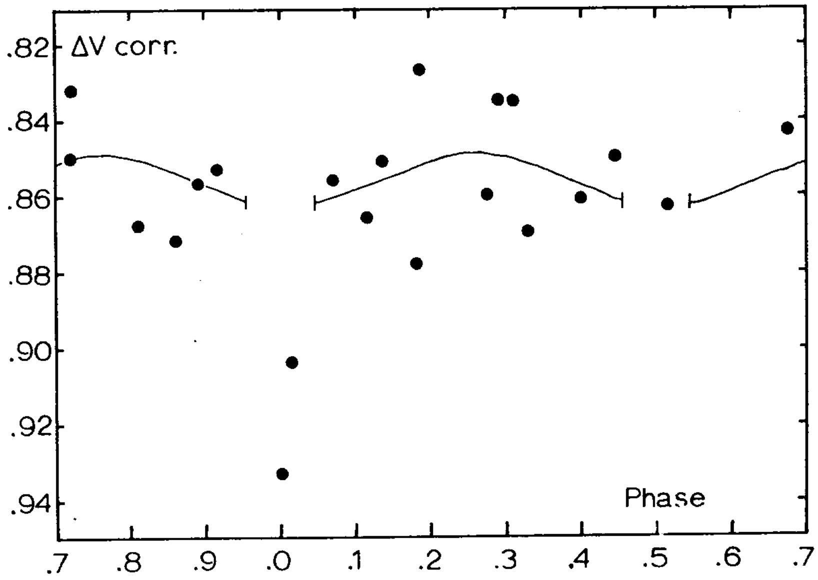

Figure 2

The ordinate is ΔV corrected by removing the migrating wave; phase is computed with equation (1). The solid curve is a cos 2θ Fourier fit showing presumably the ellipticity effect, with zero phase at the conjunction corresponding to primary eclipse. In this figure the two eclipse points do coincide because here 0.8795 days is the orbital period. We see no trace of a secondary minimum.

the variation, JD(min.) is the Julian date of the minimum which corresponds to conjunction with the G0V star behind, and O-C is the residual with respect to the ephemeris in equation (1). Because these times of conjunction should be logically equivalent to times of mid primary eclipse, it is not surprising that the O-C residuals are close to zero vis a vis their uncertainties.

All 21 ΔV values, with the wave removed as we discussed, are plotted in Figure 2, where phase is computed with the ephemeris in equation (1). The solid curve is the cos 2θ wave with a full amplitude of $0^{m}.0136$. The interrupted portions allow for eclipses, which Bakos and Tremko say are approximately 2 hours in duration. Note that, because we are using the orbital period here, our two eclipse points do coincide very near zero phase. Although our phase coverage is not dense, we note no trace of a secondary eclipse around phase $0^{p}.50$.

The 1978 periastron passage should have produced an interesting glitch in the O-C curve similar to that seen in QS Aquilae, another eclipsing binary in a highly eccentric long-period orbit around a third star, by Knipe (1971). From parameters in table II of Batten et al. we can estimate that the amplitude of such a glitch should have been only about $0^d.001$ or $0^d.002$. The only times available to establish the course of the O-C curve before the JD 2443669.24 periastron were the two of Scarfe, closely spaced in time ($\Delta n = 24$ cycles) and both relatively uncertain (± $0^d.007$). Our recent times add little statistical weight in defining the course of the O-C curve after periastron. Therefore, unfortunately, the available data are incapable of revealing this small effect. The amplitude of the glitch Knipe saw in QS Aql, $0^d.07$, was considerably larger.

Our finding of a migrating wave in the light curve of V772 Her explains the curious photometric behavior outside eclipse which Scarfe noticed but did not explain. The 0.75% difference between $0^d.8795$ and $0^d.873$ would explain why Scarfe found the variation correlated approximately but not exactly with orbital phase. Bakos and Tremko noticed similar behavior but explained certain aspects of it by imagining the M-type component a T Tauri star filling its Roche lobe, transferring matter onto the G0V star, and producing a hot spot at the point of impact. We, however, believe the $0^d.873$ variability arises from a not-quite-synchronously rotating star whose surface is darkened unevenly by regions of starspot activity, as is virtually always the case in chromospherically active stars which show strong Ca II H and K emission in their spectra. The star responsible is surely the G0V component, because the G5V component (although it shows H and K emission also) has Doppler broadened lines which imply a rotation period of 2 or 3 days, very different from $0^d.873$. Note that the wavelength dependence of the Δm values in both Table II and Table III is such as to have arisen from the G0V star, i.e., the hottest of the three in the triple system.

This extremely interesting triple system would profit from more thorough photometric coverage which could yield a solution of the light curve for the geometrical parameters of the G0V + M1V system. Such photometry should cover the phases of both primary and secondary eclipse, although the latter may prove undetectable. It should cover the phases outside eclipse simultaneously, so that the photometric complication of the migrating wave can be removed before solution. And the photometry should be multicolor, to help in removing the third light contributed by the G5V star.

We acknowledge support provided by N.S.F. research grant AST 84-14594.

LOUIS J. BOYD
RUSSELL M. GENET
Fairborn Observatory
629 North 30th Street
Phoenix, Arizona 85008

DOUGLAS S. HALL
WILLIAM T. PERSINGER
Dyer Observatory
Vanderbilt University
Nashville, Tennessee 37235

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