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THE LIGHT CURVE OF V 441 HERCULIS

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ABSTRACT

The light variations of the F-type supergiant V 441 Her have been followed for a period of five years in the B and V pass bands. A pulsation period of 63.9 days has been derived. The residuals show a harmonic distribution with a period of about 1500 days. Arguments are presented in favour of a circumstellar envelope around the F-type star and an infrared companion to this star.

INTRODUCTION

V 441 Her (89 Her, HD 163506) is a relatively bright star (V = 5.45) of spectral type F2eIa and an absolute visual magnitude of -7.1 (*Searle* et al., 1963). A light curve with an amplitude of 0.1 mag. and a period of about 70 days has been derived by *Worley* (1956). Variations in radial velocities have been noted by *Campbell* and *Moore* (1928). Spectroscopic orbital elements were derived by *Ferro* (1983) with a period of 286 days. During the last ten years the star has been the subject of numerous photometric observations by *Percy* et al. (1979), *Burki* et al. (1980), *Fernie* (1981) and *Percy* and *Welch* (1981). The present author has discovered the star accidentally by choosing it as a comparison star in a program of photoelectric observations of some visual binaries.

As has already been pointed out, spectroscopic observations yield a period of 286 days for the radial velocity variations. From orbital elements derived by *Ferro* (1983) it appears that a massive primary star of 20 solar masses has a companion of about 2 $M_{\odot}$ at a distance of nearly 3 AU. A line splitting of the H and K lines, of Hβ and of the D lines has been observed indicating a presence of a circumstellar envelope (*Gillett* et al., 1970). From IUE high resolution ultraviolet spectra *Lamb* and *Neese* (1982) have found evidence for mass loss from the star. On the other hand *Humphreys* and *Ney* (1974) concluded that 89 Her may be a binary system having an infrared star at a distance of about 9 AU.

OBSERVATIONS

The present series of photometric observations has started in the spring of 1981 and continued yearly, with the exception of one year (1985) until the summer of 1986. The observations were made with the 0.3 m reflector of the University of Waterloo equipped with a thermoelectrically cooled photometer and an EMI 9844B photomultiplier tube. The observations were made in the B and V pass bands. On each night a series of measurements of the comparison star, the variable and the check star were made. The variable was compared with the star HD 165908 of spectral type F7V and checked against the star HD 162555 of spectral type K1III. A differential extinction correction has been applied to the observations. The following magnitude difference between the comparison star and the check star has been derived:

$$B = -0\overset{m}{.}974 \pm 0.003 \qquad V = -0\overset{m}{.}532 \pm 0.003$$

The light curve of V 441 Her is that of a small amplitude pulsating variable with a period given by a number of authors as 63 to 72 days. From sources listed above 17 epochs of maximum brightness have been extracted and a least squares solution performed to derive corrections to the assumed zero epoch, the period and its derivative. The following elements have been obtained:

$$\text{Max.} = \text{J.D. } 2444395.1723 + 63\overset{d}{.}93296 \cdot E + 0\overset{d}{.}000067914 \cdot E^2$$
$$\pm.0027 \qquad \pm.00012 \qquad \pm.000000008 \text{ (m.e.)}$$

The photoelectric observations made at Waterloo have been listed in Table I while the epochs of maxima used in derivation of the period have been reproduced in Table II. The residuals from the above ephemeris, especially those of the last ten years exhibit an oscillation in the range of ± 20 days with a period of about 1950 days (the average separation between maxima and

Table I

Photoelectric observations of V 441 Her

J.D.	Phase	V	B-V	J.D.	Phase	V	B-V
2440000+				244000+			
4745.854	0.4661	5.336	0.531	5540.665	0.7384	5.248	0.463
4760.792	0.6989	5.289	0.495	5549.601	0.8767	5.242	0.457
4773.724	0.9004	5.240	0.499	5554.569	0.9536	5.255	0.480
4781.757	0.0255	5.268	0.484	5567.560	0.1391	5.309	0.478
4782.700	0.0402	5.256	0.496	5571.553	0.2009	5.294	0.518
4795.634	0.2418	5.302	0.511	5578.544	0.3090	5.338	0.483
4796.659	0.2577	5.308	0.508	5585.535	0.4172	5.356	0.491
4807.630	0.4287	5.368	0.534	5592.530	0.5254	5.318	0.522
4808.621	0.4441	5.355	0.539	5819.868	0.9314	5.252	0.492
4810.607	0.4750	5.350	0.534	5836.798	0.3390	5.338	0.525
4815.608	0.5530	5.338	0.534	5844.803	0.4638	5.352	0.498
4817.634	0.5845	5.317	0.531	5853.774	0.6037	5.318	0.499
4828.599	0.7554	5.244	0.474	5855.775	0.6350	5.328	0.485
4876.565	0.5003	5.351	0.551	5870.725	0.8681	5.252	0.470
4880.606	0.5632	5.344	0.550	5872.722	0.8992	5.252	0.469
4881.591	0.5786	5.308	0.550	5880.676	0.0233	5.245	0.492
4890.565	0.7184	5.276	0.500	5882.686	0.0346	5.252	0.472
4894.582	0.7809	5.238	0.526	5887.660	0.1322	5.264	0.489
5087.854	0.7720	5.246	0.497	5893.660	0.2258	5.289	0.496
5140.740	0.5943	5.328	0.532	5894.636	0.2410	5.297	0.491
5144.710	0.6560	5.290	0.519	5900.649	0.3348	5.329	0.487
5151.672	0.7642	5.258	0.543	5907.615	0.4434	5.330	0.498
5158.720	0.8738	5.246	0.506	5909.590	0.4742	5.316	0.515
5217.594	0.7819	5.223	0.479	5928.568	0.7707	5.267	0.519
5220.544	0.8278	5.217	0.479	5929.562	0.7856	5.259	0.473
5221.536	0.8432	5.240	0.482	5934.565	0.8637	5.244	0.458
5222.550	0.8589	5.242	0.484	5937.554	0.9103	5.215	0.463
5243.522	0.1766	5.311	0.497	6550.840	0.6796	5.270	0.506
5247.514	0.2386	5.322	0.502	6558.814	0.7436	5.219	0.527
5248.517	0.2542	5.365	0.489	6580.756	0.0858	5.255	0.528
5264.531	0.5029	5.320	0.531	6584.742	0.1480	5.287	0.522
5266.500	0.5335	5.323	0.509	6591.729	0.2570	5.319	0.536
5269.500	0.5800	5.316	0.540	6598.715	0.3659	5.361	0.540
5470.822	0.6570	5.277	0.506	6599.700	0.3813	5.362	0.531
5506.800	0.2140	5.311	0.503	6606.690	0.4903	5.353	0.531
5507.693	0.2278	5.314	0.481	6621.668	0.7238	5.284	0.503
5525.639	0.5057	5.308	0.513	6634.621	0.9258	5.266	0.502
5537.660	0.6918	5.265	0.452				

minima). The distribution of residuals is shown in Figure 1a. Subsequently, the residuals have been fitted to the following expression:

$$(O-C)_1 = A\cdot\sin 2\pi\left(\frac{P_o}{P_1}E - \varphi\right)$$

where P_o is the pulsation period and P_1 is the period of oscillation while φ is the phase shift. By the method of least squares the following elements have

Table II

Epochs of maxima of V 441 Her and their residuals

J.D.	Δt	E	$(O-C)_1$	$(O-C)_2$	Source
2435308.72	-9087.024	-142	18.612	- 8.015	Worley, 1956
5386.63	-9009.114	-141	32.398	5.995	-"-
8894.548	-5501.196	- 86	12.937	3.274	Burki et al., 1980
2441398.675	-2997.069	- 47	16.768	4.978	-"-
1458.519	-2937.225	- 46	12.488	- 0.198	-"-
3316.74	-1079.004	- 17	11.107	5.787	Fernie, 1981
3452.487	- 943.257	- 15	18.606	11.496	-"-
3689.705	- 706.039	- 11	- 0.673	- 8.724	Percy et al., 1979
4060.656	- 335.088	- 5	-14.467	-16.511	Fernie, 1981
4395.744	0	0	0	0.572	Percy and Welch, 1981
4455.592	59.848	1	- 4.276	1.909	-"-
4522.528	126.784	2	- 1.465	5.542	Ferro, 1983
4704.899	309.155	5	-11.466	- 3.584	-"-
4773.724	377.980	6	- 6.765	0.865	present paper
4828.599	432.855	7	-16.014	- 8.887	-"-
4894.582	498.838	8	-14.156	- 7.751	-"-
5221.536	825.792	13	- 7.823	- 6.768	-"-
5549.601	1153.857	18	- 0.379	- 2.745	-"-
5877.696	1481.952	23	7.095	7.475	-"-
5937.554	1541.810	24	2.829	4.450	-"-
6558.814	2163.070	34	-17.153	- 3.645	-"-
6636.621	2240.877	35	- 3.470	10.189	-"-

been derived:

$$A = 6\overset{d}{.}532 \pm .012 \qquad \varphi = 135\overset{\circ}{.}685 \pm .012 \text{ (m.e.)}$$

The new residuals appear to have a more random distribution with a scatter of about ± 10 days. The sum of the squares of the residuals has been reduced to 1083 from 3760. Some of the large residuals may have been produced by inclusion of inadequately observed epochs of maxima.

The observations made between 1981-86 have been represented in terms of the 64-day period, including the quadratic term in Figure 2a. The light curve reached a maximum at phase 0.85 and a minimum at phase 0.40. Its amplitude is 0.12 mag. The individual points exhibit a scatter of about 0.02 mag. with respect to the mean light curve. The colour index, B-V, shows a considerable scatter. Therefore its mean value for every tenth of the phase interval has been calculated and plotted in Figure 2b. The open circles represent the mean of fewer than five points in a given phase interval. The plot shows that the colour index changes with the light curve becoming bluer at the time of maximum brightness of the light curve with, perhaps, a small phase delay as compared with the light curve itself.

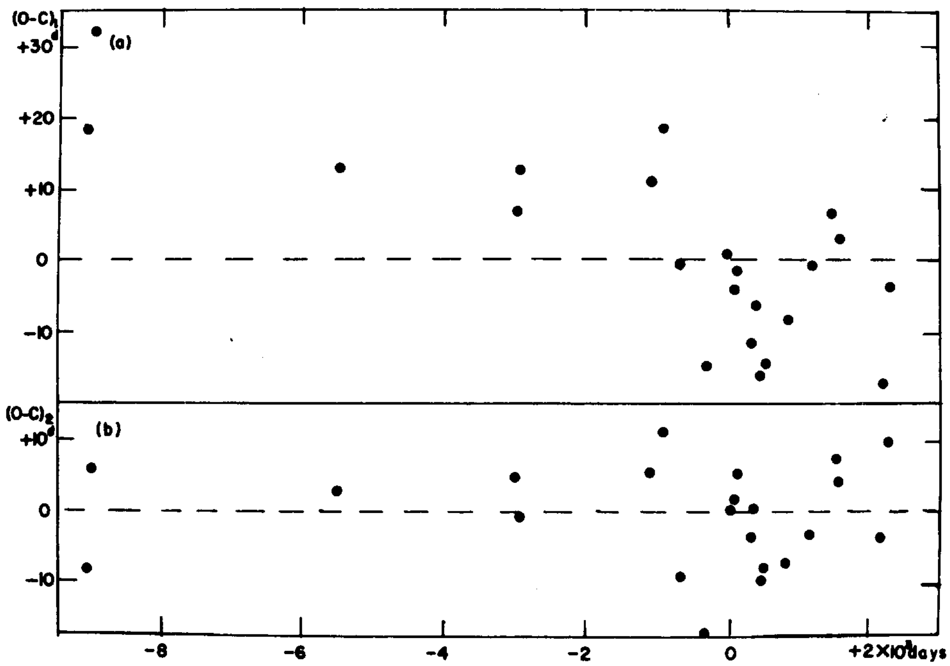

Figure 1a: The residuals $(O-C)_1$ of Table II including the quadratic term of the ephemeris
1b: The residuals $(O-C)_2$ including the harmonic term

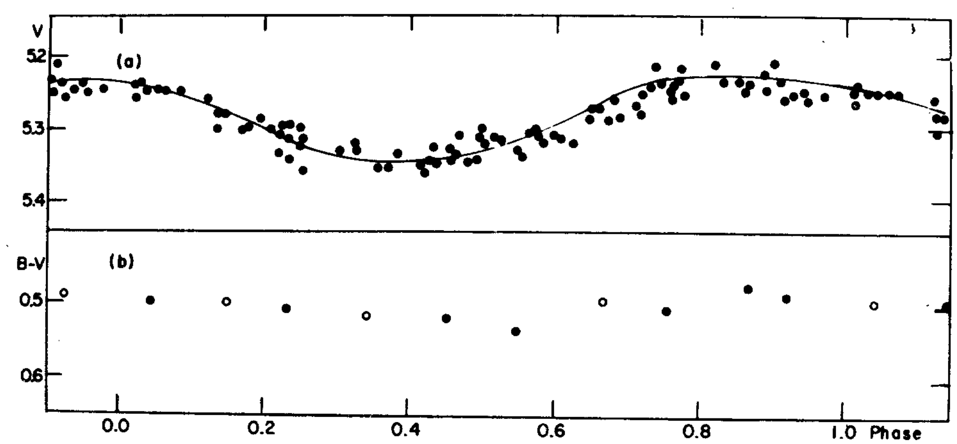

Figure 2a: The light curve of V 441 Her
2b: The colour index (B-V) of V 441 Her

DISCUSSION

In the preceding section it has been shown that the period of light variations of 89 Her is variable and a second order term is required to represent the light curve of the star over a long period of time. Coupled with the line doubling of certain spectral lines observed by *Böhm-Vitense* (1956) and more recently by *Lamb* and *Neese* (1982) an expansion velocity of about 200 kms^{-1} has been observed. This velocity may represent the escape velocity at the stellar surface. It indicates an ejection of a gaseous shell and a formation of a circumstellar envelope around the F-type supergiant. *Sargent* and *Osmer* (1969) have estimated the mass loss to the envelope at about 10^{-8} $M_{\odot}$/year. In addition, *Humphreys* and *Ney* (1974) have measured an infrared excess in the radiation of this star and concluded at the presence of a late type supergiant having an orbital period in excess of 4 years. The distribution of the residuals in Figure 1a confirms the presence of a star in the system. By assuming the mass of the F-type supergiant to be about 20 $M_{\odot}$, the mass of the infrared star as 10 $M_{\odot}$ and the orbital period as 5.3 years (1950 days) the semimajor axis of the orbit is about 9.3 AU.

Thus we conclude that the system of 89 Her is at least a triple system having a small mass component orbiting the F-type supergiant with a period of 285 days. At the same time the pulsating supergiant is loosing mass to a circumstellar envelope. In addition there is a late type supergiant orbiting the system with a period of about 5.3 years.

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