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The triple system HD 165590: a spectroscopic and photometric study

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Abstract. — A detailed study of the system V772 Her = HD 165590 = ADS 11060 AB is presented. The three identified components are found to be late type stars close to the zero-age main sequence with high rotational velocities. Spectroscopic observations allowed a quantitative determination of stellar activity indicators for the two members of the close binary as well as for the visual companion. An estimation of the most relevant physical parameters has been derived from the colour indices of each of the components and the close system has been found to be an eclipsing binary. This additional source of information combined with published measures of radial velocities, provides the absolute dimensions of the component stars (1.1 and 0.6 solar masses, and 0.9 and 0.6 solar radii) which confirm that the system is very little evolved. Moreover, a distance of 32±4 parsecs has been found to V772 Her in good agreement with available trigonometric determinations. Finally, we have compared these results with evolutionary models for main sequence stars of solar chemical composition.

Key words: binaries — stellar activity — *uvby* photometry — spectroscopy — emission lines.

1. Introduction.

V772 Her = HD 165590 = ADS 11060 AB is a very rewarding system composed of three main sequence stars with unusual rotational velocities. Many authors have investigated the visual binary (AB) since the pioneer paper by Aitken (1923) until the last periastron passage in 1978. With more spectroscopic data, Batten *et al.* (1979) and Heintz (1982) obtained an accurate determination of the orbital parameters.

The single-lined spectroscopic binary Aa, b undergoes shallow eclipses (Scarfe 1977 and Boyd *et al.* 1985) with additional variations outside eclipse due to the presence of active dark regions in the stellar photosphere. The derived photometric period suggests a synchronous rotation of the inner orbit (Aa, b) in good agreement with the measured rotational velocity for the Aa component.

Stern & Skumanich (1983), reported on the high energy picture using IUE lines clearly seen in emission. Additional data in the Ca II lines (De Castro *et al.* 1990), the measurements at 6 cm ratio wavelenghts (Drake *et al.* 1986) and the X-ray fluxes (Landini *et al.* 1985) complete the general picture for BY Dra and RS CVn systems.

The extremely high rotational velocities of the brighter component (Aa) of the spectroscopic binary and the visual companion (both G-type stars), supports the idea of an enhanced magnetic activity with the associated mechanisms of non-thermal heating for the lower chromospheres and coronas. The age of the system has been evaluated by Fekel (1981) to be around 10^8 years from the Li/Ca I relation.

The aim of the present paper is to use new observational data as well as those already available to get accurate values of the most relevant physical parameters for the system and analyze, within this frame, the observed values of different activity indicators.

In section 2 we present the new *uvby* and Hβ photometry. Physical parameters for the components are discussed in Section 3 showing a triple system with astrophysical parameters typical for G and late K main sequence stars. The spectroscopic data are presented in Section 4. The emission fluxes derived and associated parameters are discussed in Section 5. Evidences supporting the idea that the activity is mainly concentrated in the two main-sequence G-type stars are given.

A final discussion of the system is included in Section 6, showing a triple system composed of three young late-type main sequence stars with extremely high rotational velocities and associated activity parameters in good agreement with the expected values from the measured velocities.

2. The photometric observations.

uvby and Hβ observations of V772 Her have been carried out during 10 nights in july 1988 at the Calar Alto Observatory (Almería, Spain) located at 2168 meters over the sea level. The 1.23 telescope, operated by the Max Planck Institut fur Astronomie, equipped with a multipurpose two channel photoelectric photometer and Stromgrem *uvby* as well as Crawford's narrow and wide filters centered in the Hβ line, was used. The measurements were made within the framework of a monitoring campaign of RS Cvn and BY Dra active binaries.

A set of 9 red standard stars from the compilation of Perry *et al.* (1987) was observed on a selected sample of nights (4) with good atmospheric conditions, to obtain the standard transformation coefficients for the *ubvy* and Hβ systems and standardize the comparison stars. A detailed description of the observational techniques and reduction procedures can be found in Reglero *et al.* (1987, 1988).

The observations of V772 Her were obtained differentially with respect to C1=HD 165825 and C2=HD 165569 used as comparison and check stars, and for which we have obtained the following average values:

	V	$(b-y)$	m_1	c_1	N	β	N
$C1$	7.506	0.758	0.531	0.475	33	2.567	90
σ	17	6	15	18		8	
$C2$	7.618	0.185	0.193	1.079	14	2.810	35
σ	15	5	9	12		7	

σ is the RMS dispersion and N the number of measurements.

For the *uvby* photometry the instrumental differences, corrected for atmospheric extinction, were transformed to the standard system by means of the scale coefficients. They were then added to the $C1$ values, to obtain the standard values. The Hβ data are obtained from instrumental ones by means of the standard transformation procedure.

A plot of the observations using the ephemerid given by Bakos & Tremko (1982) indicated that V772 Her was in eclipse during three nights. Using these additional information, a least-squares fitting provided the adopted new ephemerid:

$$\mathrm{JD} = 2447372.568 + 0\overset{\mathrm{d}}{.}8795045\ E$$

Normal points (using a bin size of 0.025 in phase) were constructed. In Table 1, we present final values in V band $(b-y)$ color and m_1, c_1 and β indices for V772 Her. Points marked with E correspond to eclipse. N is the number of individual measurements and σ is the RMS for the mean.

The constancy of the comparison stars was checked every night giving internal RMS errors of 0.012, 0.008, 0.020, 0.030 and 0.013 for the V band, $(b-y)$ color and m_1, c_1 and β indices respectively. Looking at the mean RMS values obtained for the normal points outside eclipse of 0.010, 0.006, 0.019, 0.029 and 0.008 for the same bands, colors and indices, we can conclude that the normal points computed are free of effects of short term variations due to the activity and are in good agreement with the internal accuracy of the photometry given by the comparison stars.

Next we use least squares to fit a truncated Fourier series of second order to the magnitudes outside eclipse for the V band, $(b-y)$ color and m_1, c_1 and β indices. The Fourier coefficients are given in Table 2. The plots are given in Fig. 1 to 7.

For the V filter (Fig. 1) it is easy to see a non-symmetrical variation of the light outside eclipse of amplitude ΔV = 0.05 mag., $\Phi_{\min}$ =0.08 and $\Phi_{\max}$ =0.67. In Figure 2 we present the plot of the amplitudes against time for our data and the published amplitudes given by Boyd *et al.* (1985) and Strassmeier *et al.* (1989) for the years 1983, 1984 and 1986, showing a nearly constant behavior in time with a mean value of ΔV =0.07 $\pm$ 0.02. In Figure 3 we present the plot of the amplitudes ΔV against the phase of the minimum computed with the ephemerid of equation (1) showing the migration of the minimum of light towards increasing orbital phases.

Despite the non-symmetrical shape of the light curve, indicating the presence of more than one active center on the star's surface, it seems to be clear that there is a good correspondence between the orbital and photometric periods in disagreement with very early results published by Boyd *et al.* (1985), that found marginal differences between photometric and orbital periods.

Assuming the model of mass transfer between the cool component of the spectroscopic binary onto the hot component producing a unique hot spot at the impact point proposed by Bakos & Tremko (1982), it is not easy to explain the asymmetries of the light curve and the migration of the wave from Figures 1 and 3.

We therefore conclude that the orbital and photometric periods are the same (within uncertainties) and the observed variations in the light outside of eclipse are due to the presence of different activity centers with complex geometries on the star surface, that can mask the true photometric period of 0.8795 d.

For the $(b-y)$ color the amplitudes of the Fourier coefficients are within observational uncertainties and only a small and very marginal indication that the star tends towards redder when darker is found from Figure 4. A similar behaviour is shown for the m_1 and β indices from Figures 5 and 6. m_1 is constant in phase and β shows only a tendency to lower β at minimum of light phase.

The plot of c_1 *versus* orbital phase given in Figure 7, shows a more complex behaviour with differences Δc_1 = 0.08 between phase 0.9 and 0.4 that is in the 2σ level of error. Due to the previously referred constancy of the m_1 index and $(b-y)$ color in this spectral region, the observed variations can only be interpreted as increments in the flux in the u filter close to the minimum of light. This increment is in good agreement with the enhanced chromospheric heating by filling in the absorption lines present in this filter. In any case, the scatter in the data and uncertainties are too high to conclude the presence of real variations in this index. More accurate observations are needed to confirm the real flux increase in the u band.

3. Astrophysical parameters.

3.1. Photometric calibrations

Before embarking on the determination of the absolute parameters for the eclipsing binary (A), we are going to discuss the photometric properties of the system as a whole (AB) as well as the visual component (B) as an isolated case, in order to get the maximum valuable information on the individual components of the eclipsing binary (Aa, Ab).

Using the mean values outside of eclipse from Table 2 for colors and indices, the maximum of light V =7.024 mag. and taking the standard calibration procedure given by Crawford (1975) with the extension by Olsen (1988) up to β >2.590, we have computed the interstellar reddening. An excess of $E(b-y)$ =0.02 ± 0.02 was derived in good agreement with the expected value for this region of the sky and the assumed distance. After correction, the reddening free magnitudes, indices and colors for the combined system are, V =6.94, $(b-y)$ =0.393, m_1 =0.197 and c_1 =0.273.

In order to derive the absolute magnitude M_v, according to Crawford (1975), and metal content, [Fe/H], using the calibrations of Nissen (1981), we have computed the δm_1 and δc_1 parameters, giving values of δm_1 =0.031 and δc_1 =0.001. The computed absolute magnitude is then M_v =6.94 mag and the metallicity [Fe/H]=−0.13. Next step in our calculations have been done using the empirical calibration of effective temperature $T(\beta)$ from Saxner and Hammarback (1985), and the visual surface flux $F_v(b-y)$ calibration by Moon (1985). The effective temperatures and visual fluxes are given in Table 3. Using the spectroscopic distance π=0.025 determined by Heintz (1982) and the basic relations (Schmidt-Kaler 1982) between the parameters previously determined , M_v, T and F_v, with the bolometric magnitude and radius, we have computed the rest of the astrophysical parameters listed in Table 3. The mass has been taken from Heintz (1982). The listed errors have been estimated from the accuracy of the photometric calibrations and error formulae.

A comparison of the astrophysical parameters given in Table 3 (excluding the mass) for the whole system (AB) with the mean relations for main sequence stars compiled by Schmidt-Kaler (1982), allow us to conclude that it can be considered as an average G3V star with a moderate underabundance of metals measured through the m_1 index. This apparent metal deficiency is a common feature of the chromospherically active systems, rather related with the degree of activity than with real metal underabundances. (Giménez *et al.* 1990). The extremely good agreement between the computed c_1 index and the calibration value, giving a δc_1 =0.001, supports the deduction made by Batten *et al.* (1979), that all the components of the system are on the main sequence and close to the ZAMS line. This result will be used later to constrain the family of possible solutions for the individual components. Finally the $(B-V)$ color has been computed as a function of $(b-y)$ using the empirical calibration of Cousins & Caldwell (1985), giving a value $(B-V)$ =0.65 according with the observed value reported by Eggen (1965).

For the B component, we have used the observed difference of apparent visual magnitudes $\Delta(B-A)$ =0.7 mag. and the distance π=0.025, in order to derive the apparent and absolute magnitudes listed in Table 3. Assuming a spectral type G5V that is in good agreement with the previous absolute magnitude determination, mass $M = 0.95 M_\odot$ (Heintz 1982), and main sequence class of luminosity derived thorough the $\delta c_1(AB)$ =0.001, we have computed the values of $M_{\rm bol}$, $T_{\rm eff}$ and radius listed in Table 3. The F_v =3.748 ± 0.02 parameter used in this calculations has been taken from Popper (1980). In this calculation, obviously, the main source of error arises from the assigned value for the visual flux taken from the spectral type. Nevertheless the error asigned at this parameter of 0.02 mag. that corresponds to ±1 subspectral types, is a very conservative quantity for the accuracy of the absolute magnitudes and masses observed. Despite the magnitude of the errors assigned to the derived astrophysical parameters, the B component can be considered as a G5 main sequence star in good agreement with the spectral type assigned to this star.

3.2. Light curve analysis

An important source of information provided by V772 Her is the observation of a primary eclipse. In Figure 1, a plot of the photometric variations with phase is shown. After correcting for the outside-eclipse light variations due to the presence of spots and discussed in the previous Section, as well as the contribution of the third $(B, L_3$ =0.40), the eclipse parameters can be summarized as follows: a primary eclipse is observed with a depth of 0.09 mag. in filter y and a duration of 0.076 in phase while no secondary eclipse is detectable

As discussed by Garrido *et al.* (1983), in the case of the β Cephei eclipsing binary system 16 Lac, a simple procedure based on the method by Russell & Merrill (1952) for light curve analysis can be applied. Assuming $L_1 = 1$, as suggested by the absence of secondary eclipse, and expressed through,

$$L_2 \alpha_c^{\rm tr} = 0.000 \pm 0.005,$$

it can be deduced immediately that, according to the observed depth of the primary eclipse,

$$\tau\alpha_o^{tr} = 0.080 \pm 0.008,$$

and, consequently a lower limit for the ratio of radii k may be established at around 0.28. An upper limit is given, under the assumption of main-sequence normal components, by the luminosity ratio and absence of secondary eclipse.

Further use of equations (1) to (4) of Garrido *et al.* (1983), adopting a value for the linear limb darkening of the eclipsed star of 0.6, allows us to estimate the involved geometrical elements. Because of the complex form of the interdependence between the different geometrical and auxiliar parameters, k can only be deduced by means of successive interactions. The observed semi-duration of the eclipse provides the external tangency phase $\theta 1$=13.6 ± 0.8 degrees. Table 4 summarizes the results for the case of different assumed values of k.

In order to find out the most appropriate value of k, more information is actually needed. This is certainly provided by the spectroscopic and photometric observations. If both components are normal main sequence stars, the observed mass ratio of 0.6 should require a similar value of the ratio of radii according to Giménez and Zamorano (1985). Using the derived values of the effective temperatures in previous Section and evolutionary tracks by Claret and Giménez (1989) with standard solar chemical composition for the main sequence, permit us to estimate k =0.64 ± 0.04, (r_1 =0.21 and i =75).

Since the adopted procedure is too simple for the level of approximation required, we have further attempted to reproduce the observations by means of synthetic light curves. Preliminary results shown above, clearly indicate the system to be well detached and we have therefore adopted the code EBOP (Popper & Etzel 1981) based on the model by Nelson & Davis (1972). The derived effective temperatures (see Table 3) indicate linear limb-darkening coefficients of 0.66 and 0.8 for the hot and cool star, respectively. Furthermore, the surface brightness ratio, corrected for lim-drakening, as given by Popper (1980), corresponds to J_2/J_1 =0.125 for ΔF_v =0.219.

With these parameters adopted, we have computed a grid of theoretical light curves for different values of the radius of the hot component and the orbital inclination. The best fitting to the observations is given by,

$$r_1 = 0.195 \pm 0.010, \qquad (r_1 + r_2 = 0.318)$$
$$i = 76.2 \pm 0.7,$$

which implies total normalized luminosities of 0.954 and 0.046 for the hot and cool star, respectively. This is in good agreement with results discussed above and shows little discrepancies with respect to the estimations based on the method by Russell & Merrill (1952) despite the crude assumptions involved, (L_2 =0.0, mainly).

In order to allow the estimation of errors in the determined geometrical parameters, in Table 5 we present the results for the best fit in depth, duration and shape to the observed primary eclipse for different adopted values of the ratio of the radii. Notice the small dependence of r_1 on k, within reasonable limits.

Using now the obtained relative radii and orbital inclination with spectroscopic data by Heintz (1982), and the temperatures adopted in Table 3, we derive the absolute dimensions and distance given in Table 6.

The obtained photometric distance is found to be in good agreement with the inaccurate trigonometric determination (0.018 ± 0.012) and the previously-adopted spectroscopic parallax (0.025). Absolute dimensions were compared with standard evolutionary tracks for the main sequence with solar chemical composition (X, Z) = (0.70, 0.02) and found to be well within the observational errors for the ZAMS.

4. Spectroscopic observations.

We have taken 10 spectra centered at 3950 Å and covering 222 Å in July 1988 during a four nights run using the INT telescope (2.5 m) at the Observatorio del Roque de los Muchachos (La Palma, Spain). The spectrograph used was the IDS with the 2400B grating an camera 2 mounting the IPCS detector. Two more spectra were taken in July 1989 at the Centro Astronómico Hispano-Alemán of Calar Alto (Almería, Spain) using the 2.2 m telescope equipped with the coudé B& C spectrograph and a CCD (RCA) as a detector. The spectral resolution achieved in both instrumental configurations is 0.3 Å/pixel determined by the slit aperture. The journal of observations is given in Table 7. The phase Φ has been computed with the new ephemerid given in Section 2.

The wavelength-calibrated spectra have been extracted from the IPCS and CCD images, using the standard reduction procedures available at the Villafranca Satellite Tracking Station Computer Center of ESA (Madrid, Spain). For a selected sample of images, an optimized extraction algorithm (Horne 1986) has been tested, finding non relevant improvements in the signal-to-noise ratio. The spectra are then corrected for atmospheric extinction by means of the semiempirical method of Hayes & Latham (1975). We have checked the results of this method with the extinction curve from La Palma Observatory and also with the photometric extinction coefficients given by Fabregat & Reglero (1990) using the *uvby* system for the Calar Alto Observatory, that includes filters with effectived wavelengths close to our spectral region. No significant differences have been found in any case.

The flux calibration is performed using 4 standard stars from the compilations of Oke & Gunn (1983) and Barnes & Hayes (1984). Night to night discrepancies found for the standard-star measurements agree within 5% . After this calibration the flux units are erg cm^{-2} sec^{-1} $Å^{-1}$. The spectra are shown in Figure 8.

Using the photometric data from Table 3 as well as the $(B - V)$ color computed in Section 3 and the calibration of Catalano & Trigilio. (1990), the continuous spectrum (above lines) can be synthetized for the three componentrs of the system. The most relevant conclusion is that the K6 star contribution is around the 1% of the total flux, then the contribution of the former star to the observed spectrum is negligible. The result of adding the synthetized spectrum for the Aa and B visual components, reproduces very well the expected continuum level over the absorption lines showing the quality of the flux calibration done.

The emission fluxes for the Ca II H and k lines are obtained by reconstructing the absorption line profile below the emission peak, following the method given Blanco *et al.* (1974), as discussed by Armentia *et al.* (1990). An estimation of errors in the emission flux measurements leads to a 25% of uncertainty in good agreement with similar calculations from Fernández-Figueroa *et al.* (1986) using the same equipement and data-reduction techniques. Final results for the emission fluxes are given in Table 8.

5. Analysis of the K and H lines of Ca II.

Focussing our attention on the spectra obtained at Calar Alto Observatory (labeled *k* and *l* in Tab. 8 and Fig. 8), two different contributions can be observed. Each contribution was extracted using a gaussian fit of the components, with results reported in table 9. The width of the K lines is 1.2 Å (FWHM) and 0.6 Å (FWHM) for the wide and narrow component respectively. Due to the differences in rotation rates between the components of the system, the wider emission contribution is assigned to the most rapidly rotating star Aa, whereas the narrower emission contribution is assigned to the B component. Since the lower luminosity of the Ab star, as discussed in section 4, we assume no measurable contributions to the observed emission reversals.

In order to check these assumptions, we have calculated from Doppler shift the difference between the radial component of the orbital velocities from the *k* and *l* spectra, obtaining a result of 156.4 km/s and 162.6 km/s for the H and K lines respectively, with an expected error of 22 km/s. The orbital parameters previoulsy computed from the photometric measurements allow us to compute the radial velocities at 0.86 and 0.28 phases (which correspond to our k and l spectra), a value of 166.0 km/s was obtained, which agrees rather well with the previous Doppler-shift computed values. According to these results, the surface fluxes for the separable components have been computed and are shown in Table 9.

We have checked the Wilson-Bappu relationship (Rutten 1987), using the K emission reversals of spectra *k* and *l*. The B component fits within errors in this calibration, while the most active and rapid rotating Aa star deviates by around 5 magnitudes.

Spectra labeled from a to j, obtained in July 1988 at La Palma Observatory have a lower S/N ratio and it is not possible in all the cases to deconvolve the emission reversals in separate gaussians, even in the K line. The spectra e, f and g seem to be the most favorable cases to attempt the Gaussian deconvolution. For these spectra we measure a narrow contribution with a FWHM=0.5 Å at λ=3933.8 Å that would correspond to the B component, and a larger reversal with a FWHM=1.2 Å with variable central wavelength (3934.3, 3934.7 and 3935.0) for the Aa component. Under these assumptions, in July 1988 run the difference of activity level between Aa and B stars was larger than in the observations of July 1989. The Aa component exhibits a constant level of chromospheric activity with an observed flux of 7×10^{-13}erg $cm^{-2}sec^{-1}$ whereas the B component was less active in 1988 ($F_{obs} = 1 \times 10^{-13}$erg cm^{-2} sec^{-1}) than in 1989 ($F_{obs} = 2.5 \times 10^{-13}$erg $cm^{-2}sec^{-1}$), we should note that this flux difference is not very significant giving the low level of activity of the B component and therefore the difficulty in separatig the weak reversals. The orbital radial velocity obtained from Doppler shifts of the K line at different phases agrees within errors with the radial velocities computed from orbital parameters at same phases, supporting our assumptions.

We can conclude that, from high quality 1989 observations we have detected two separable contributions to the H and K emission reversals, corresponding to the Aa and B stars, showing that the chromospheric activity measured through the emission reversal in the Ca II H and K lines, is a common feature in both components. From 1988 observations the B star was less active than in July 1989, however, the Aa star shows the same activity level in both epochs, being always more active than the B component.

6. Final remarks

We have obtained new *uvbyβ* photometry and Ca II line spectroscopy for the triple system V772 Her in order to derive relevant astrophysical parameters and analyze the behavior of the different activity indicators arising from the new data.

The analysis of the primary eclipse of the A component, combined with the available radial-velocity measurements and the information coming from the photometric indices show V772 Her to be a triple system with components very close to the ZAMS line. The derived absolute dimensions, radii and masses are in good agreement with generally assigned spectral types. Standard evolutionary tracks, for solar chemical composition, confirm that the system is very little evolved.

The extremely high rotational velocities, the age and spectral classification of the components, support the hypothesis that the chromospheres are heated by non-thermal mechanisms arising from dynamos working in the stellar convection zones. The Ca II spectra show well defined reversals, at least for the two more luminous G type stars (Aa and B). Significant variations with time for the emission fluxes are seen in the B component.

The presence of active chromospheres is accompanied by photometric variations outside eclipse (waves) indicating the presence of activity centers (spots) over the stellar surfaces. The assymmetries in the light curves for the V filter suggests complex geometries in the surface of the Aa component or the convolution of active complexes in both active stars (Aa and B). The previously proposed model, involving mass transfer between components with a single hot spot in the impact point, seems to be not realistic.

The coincidence between the rotational periods derived from photometric and spectroscopic data, show the presence of synchronism for the inner eclipsing system (A). Finally, a moderated "metal deficiency" measured through the δm_1 parameter has been derived in agreement with results obtained by the authors for other active binaries.

We can conclude that V772 Her is a triple system composed by three little evolved late type stars close to the ZAMS line with high rotational velocities and active centers on the stars atmospheres. The analysis of the different activity indicators derived from our photometric and spectroscopic data shows good agreement with similar results for other active binaries.

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TABLE 1. *uvby and Hβ photometry for V772 Her. Units 1. magnitude.*

φ	V	b-y	m1	c1	β	σ(V)	σ(b-y)	σ(m1)	σ(c1)	σ(β)	N
.001	7.132	.412	.123	.156	2.585						1
.005	7.129	.417	.205	.262	2.591						1
.011	7.122	.421	.194	.277	2.587						1
.015	7.136	.414	.208	.295	2.580						1
.022	7.106	.422	.229	.301	2.590						1
.025	7.092	.425	.220	.308	2.593						1
.030	7.096	.428	.191	.328	2.585						1
.031	7.078	.413	.169	.134	2.619						1
.034	7.073	.398	.165	.130	2.604						1
.039	7.054	.436	.070	.183	2.604						1
.043	7.076	.390	.144	.218	2.580	.028	.026	.025	.040	.002	2
.049	7.076	.420	.190	.240	2.589	.005	.001	.008	.007	.011	2
.090	7.078	.423	.188	.254	2.586	.018	.012	.015	.073	.007	6
.113	7.079	.417	.185	.249	2.589	.007	.007	.021	.077	.010	4
.156	7.067	.414	.209	.243	2.596	.010	.013	.044	.055	.009	6
.166	7.071	.417	.146	.281	2.589	.010	.011	.050	.088	.014	4
.241	7.070	.425	.190	.367	2.596	.014	.005	.022	.012	.010	3
.258	7.066	.417	.209	.344	2.593	.006	.007	.027	.011	.008	3
.274	7.067	.417	.212	.278	2.591	.005	.002	.005	.014	.002	3
.287	7.062	.418	.217	.280	2.595	.008	.005	.009	.005	.001	2
.325	7.063	.423	.220	.336	2.589	.004	.003	.014	.005	.002	3
.376	7.056	.417	.232	.364	2.600	.013	.012	.030	.011	.004	2
.390	7.051	.420	.200	.317	2.598	.012	.002	.022	.026	.007	4
.413	7.046	.417	.163	.332	2.582	.011	.008	.017	.029	.013	3
.480	7.052	.415	.217	.340	2.606	.013	.003	.013	.016	.005	3
.521	7.042	.410	.179	.315	2.595	.004	.004	.020	.026	.010	4
.538	7.038	.406	.197	.269	2.592	.007	.008	.012	.030	.010	3
.586	7.023	.411	.187	.242	2.595	.006	.012	.030	.010	.009	3
.638	7.037	.414	.181	.292	2.589	.007	.008	.031	.081	.008	5
.687	7.018	.404	.159	.231	2.593	.016	.006	.019	.030	.011	2
.737	7.029	.397	.165	.213	2.572	.002	.001	.004	.012	.003	3
.770	7.029	.401	.194	.244	2.591	.015	.005	.024	.030	.009	3
.801	7.037	.403	.228	.275	2.592	.004	.006	.020	.016	.008	3
.822	7.042	.415	.186	.291	2.586	.007	.004	.005	.018	.003	3
.859	7.050	.413	.193	.251	2.597	.010	.004	.011	.008	.016	4
.870	7.044	.410	.195	.242	2.584	.009	.006	.019	.031	.022	3
.896	7.050	.406	.198	.233	2.594	.008	.001	.019	.024	.004	3
.916	7.067	.403	.179	.206	2.601	.007	.001	.027	.020	.009	3
.948	7.064	.417	.197	.231	2.596	.003	.010	.005	.065	.009	2
.951	7.064	.416	.216	.258	2.590	.009	.005	.016	.109	.002	2
.953	7.065	.430	.190	.338	2.587	.007	.007	.009	.029	.004	2
.956	7.070	.422	.183	.246	2.567	.009	.005	.001	.064	.011	2
.964	7.075	.427	.187	.354	2.577						1
.970	7.084	.418	.207	.366	2.593						1
.971	7.063	.423	.171	.125	2.591						1
.975	7.090	.422	.152	.340	2.606						1
.975	7.093	.418	.201	.353	2.573						1
.978	7.092	.417	.198	.322	2.597						1
.979	7.075	.412	.189	.128	2.599						1
.983	7.114	.418	.193	.322	2.593						1
.992	7.123	.385	.154	.141	2.598						1
.997	7.113	.405	.130	.160	2.583						1

TABLE 2. *Fourier coefficients for the light curves outside eclipse.*

	a0	a1	a2	a3	a4	σ
V	7.052	0.019	0.015	0.001	0.005	0.004
(b-y)	0.413	0.007	-.004	0.014	-.003	0.007
m1	0.191	0.007	-.004	-.014	-.003	0.017
c1	0.277	0.031	-.031	-.021	-.001	0.030
Hβ	2.591	0.002	-.004	-.002	0.001	0.006

TABLE 3. *Photometric solution for V772 Her.*

	V	m	Fv	Mv	Mb	T	R	
A+B	6.94	2.67	3.750	4.95	4.74	5280	.94	G3V
			26	10	26	60	12	
Aa		1.09	3.759	4.45	4.32	5915	.90	G1V
			20	10	6	320	5	
Ab		.63	3.540	7.68	7.00	4055	.58	K6V
			20	10	11	230	5	
B	8.10	.95	3.748	5.09	4.99	5590	.91	G5V
	5		20	8	7	300	9	

TABLE 4. *Geometrical elements.*

K	τ	α0	p0	r1+r2	r1	i
0.30	0.089472	0.894	-0.79	0.286	0.220	80.4
0.40	0.166964	0.479	-0.15	0.310	0.222	78.0
0.50	0.268897	0.298	0.14	0.326	0.218	76.6
0.60	0.393434	0.203	0.32	0.341	0.213	75.3
0.65	0.463185	0.173	0.38	0.347	0.210	74.8
0.70	0.537156	0.149	0.44	0.354	0.208	74.2
0.80	0.694485	0.115	0.52	0.365	0.203	73.3

TABLE 5. *Final geometrical elements.*

k	0.60	0.64	0.68
r1	0.196	0.195	0.193
	8	8	8
i	76.6	76.2	75.7
	6	6	7

TABLE 6. *Absolute dimensions of V772 Her.*

Component	Aa	Ab
mass (mo)	1.09	0.63
	.19	.15
radius (Ro)	0.90	0.58
	5	5
log g (cgs)	4.56	4.71
	8	11
log Te (K)	3.77	3.61
	2	2
Mbol	4.79	7.34
	23	27
B.C.	-0.11	-0.80
	2	13
Mv	4.90	8.14
	24	30
Mv (system)	4.85	
	24	
distance (pc)	32	
	4	

TABLE 7. *Summary of spectroscopic observations.*

	Date	UT	JD	φ	Tel
a	1988 Jul 26	22:45	2447369.448	0.45	INT
b	1988 Jul 27	0:25	2447369.517	0.53	INT
c	1988 Jul 27	2:12	2447369.592	0.62	INT
d	1988 Jul 27	3:19	2447369.638	0.67	INT
e	1988 Jul 27	22:15	2447370.434	0.57	INT
f	1988 Jul 28	0:12	2447370.508	0.66	INT
g	1988 Jul 28	1:24	2447370.558	0.72	INT
h	1988 Jul 29	23:21	2447372.473	0.89	INT
i	1988 Jul 30	0:30	2447372.521	0.95	INT
j	1988 Jul 30	1:47	2447372.467	0.89	INT
k	1989 Jul 14	23:37	2447722.484	0.86	CAHA
l	1989 Jul 17	23:56	2447722.497	0.28	CAHA

INT: Isaac Newton Telescope (2.5m) Observatorio del Roque de los Muchachos (IAC)

CAHA: 2.2m Telescope Centro Astronómico Hispano-Alemán de Calar Alto

TABLE 8. *Summary of measured emision fluxes.*

	K		H		
	λ	F_{obs}	λ	F_{obs}	
a	3933.6	10.1×10^{-13}	3968.5	6.9×10^{-13}	
b	3933.8	10.1×10^{-13}	3968.6	9.5×10^{-13}	
c	3934.6	10.7×10^{-13}	3969.2	7.0×10^{-13}	
d	3934.6	9.0×10^{-13}	3969.3	7.8×10^{-13}	
e	3933.9	9.0×10^{-13}	3969.3	6.4×10^{-13}	
f	3934.7	8.7×10^{-13}	3969.5	7.3×10^{-13}	
g	3935.0	6.8×10^{-13}	3969.7	5.6×10^{-13}	
h	3933.7	9.8×10^{-13}	3968.5	6.3×10^{-13}	
i	3933.8	7.6×10^{-13}	3968.7	8.0×10^{-13}	
j	3933.7	10.4×10^{-13}	3968.4	8.4×10^{-13}	
k	3933.5	2.7×10^{-13}	3968.3	2.5×10^{-13}	(B)
	3934.7	7.3×10^{-13}	3969.7	4.8×10^{-13}	(Aa)
l	3932.5	6.9×10^{-13}	3967.2	3.6×10^{-13}	(Aa)
	3933.5	2.6×10^{-13}	3968.3	2.6×10^{-13}	(B)

λ in Å, fluxes in erg $cm^{-2}s^{-1}$

TABLE 9. *Gaussian fit of the emission reversals.*

Image	Line	λ max (1)	I max (2)	FWHM (1)	Area (2)	Fsup (3)
k	K (B)	3933.5	4.22	0.60	2.71	0.66
	(Aa)	3934.6	5.50	1.25	7.29	1.86
	H (B)	3968.3	4.40	0.53	2.50	0.62
	(Aa)	3969.4	3.86	1.17	4.80	1.22
l	K (B)	3933.5	3.69	0.65	2.55	0.64
	(Aa)	3932.5	5.08	1.27	6.85	1.75
	H (B)	3968.3	3.39	0.72	2.60	0.65
	(Aa)	3967.2	3.49	0.97	3.60	0.91

Notes: (1) in Å
(2) in units of 10-13 erg cm-2 s-1
(3) in units of 10+6 erg cm-2 s-1

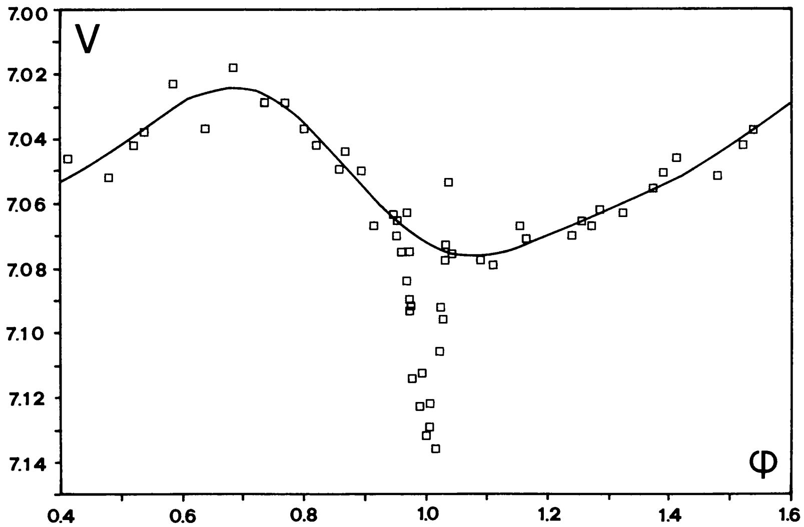

FIGURE 1. V light curve of V772 Her. Solid line represents the Fourier fit of the wave outside eclipse. Phases have been computed from the ephemerid given in Section 3.

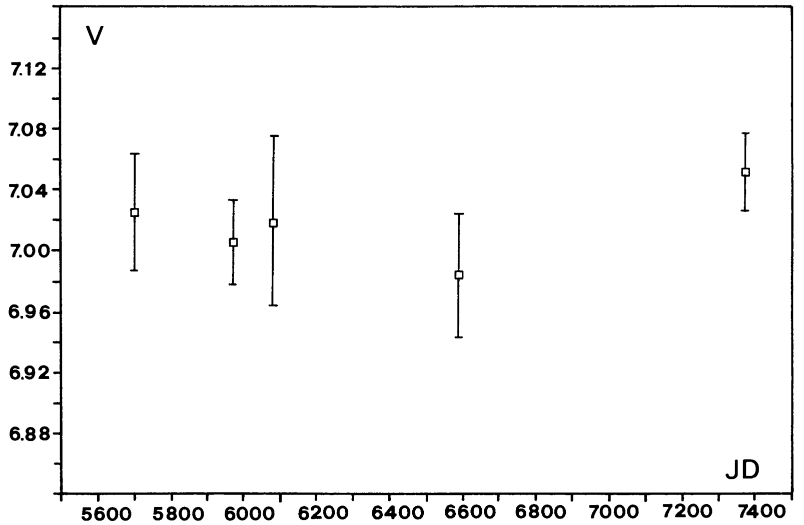

FIGURE 2. Amplitude in V of the migrating waves *versus* time. Time is given as JD-2440000.

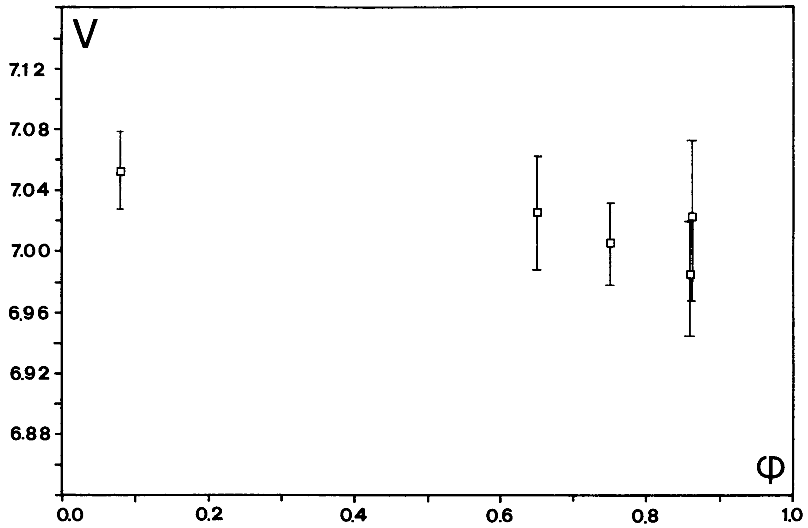

FIGURE 3. Variation of the amplitudes with phase.

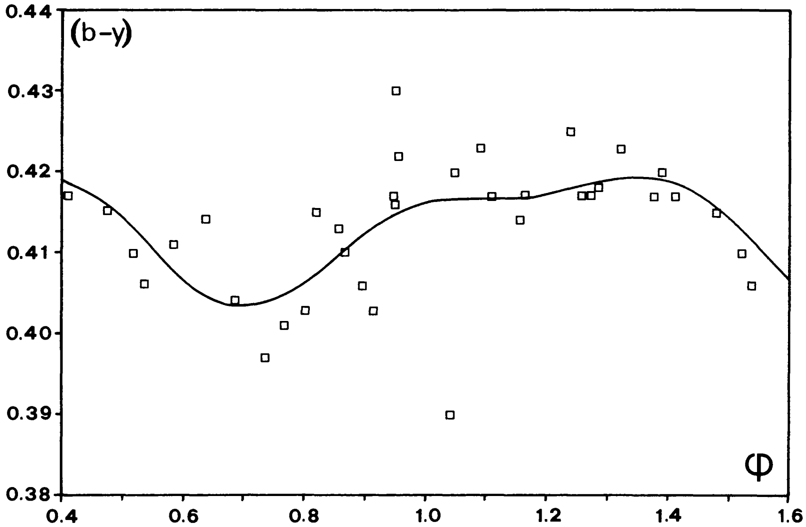

FIGURE 4. $(b-y)$-phase diagram. Solid line shows the Fourier fit of the points outside eclipse.

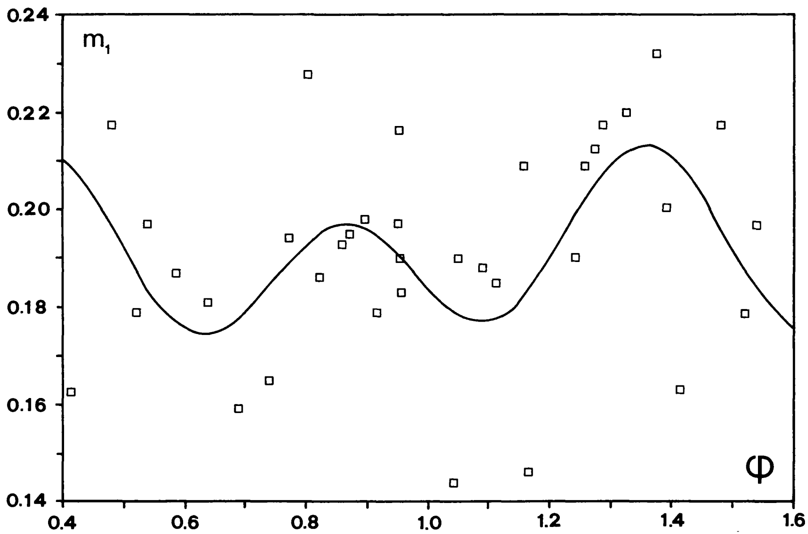

FIGURE 5. Same as Figure 4 for the m_1 index.

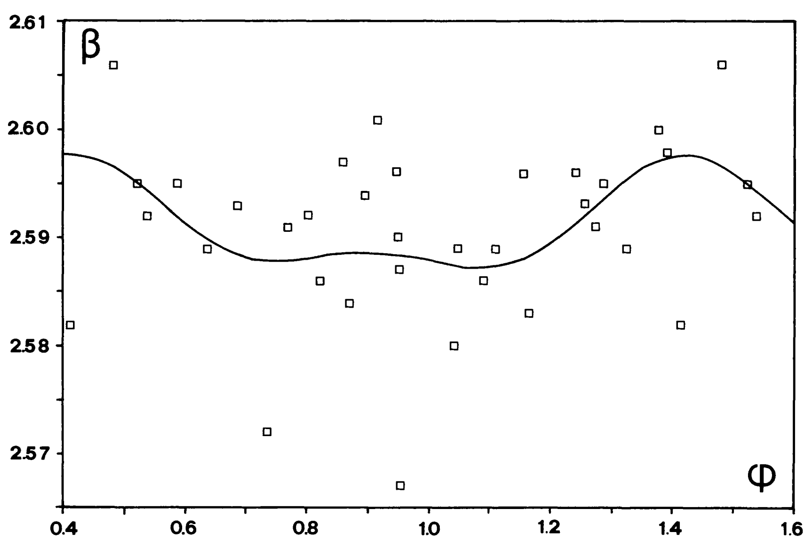

FIGURE 6. Same as Figure 4 for the β index.

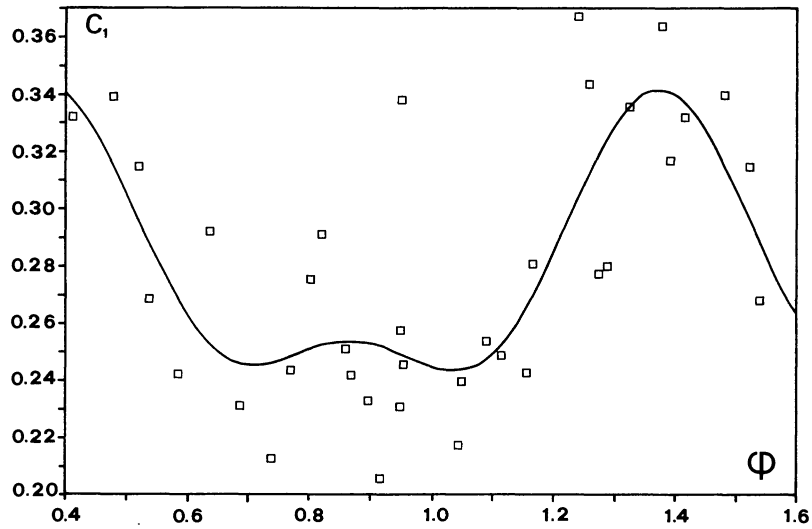

FIGURE 7. Same as Figure for the c_1 index.

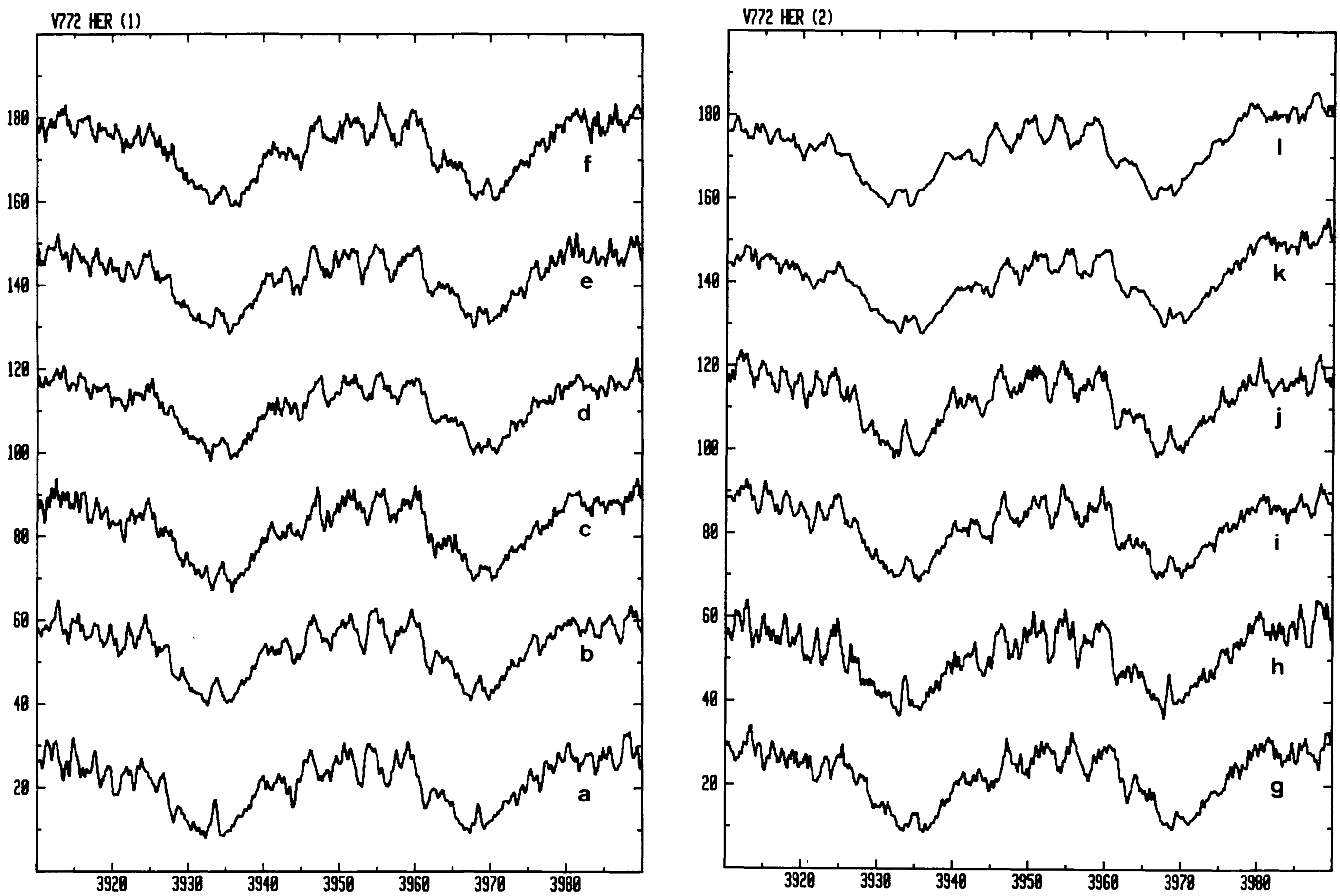

FIGURE 8. Spectra of V772 Her in the Ca II H and K range. Fluxes are in units of 10^{-13} erg. cm^{-2} s^{-1}. Individual plots are shifted with respect to the lower one by 30 units of flux to avoid overlapping.