Astron. Astrophys. 320, 101–108 (1997)

ASTRONOMY AND ASTROPHYSICS

Hα emission in the chromospherically active binary σ_2 Coronae Borealis (TZ CrB)

A. Frasca[1], **S. Catalano**[2], **and D. Mantovani**[1,3]

[1] Istituto di Astronomia, Università di Catania, Viale A. Doria 6, I-95125 Catania, Italy
[2] Osservatorio Astrofisico di Catania, Viale A. Doria 6, I-95125 Catania, Italy
[3] Visiting graduate student from Strasbourg Observatory, France

Received 2 July 1996 / Accepted 10 September 1996

Abstract. Spectrophotometry of the chromospherically active system σ_2 Coronae Borealis was obtained in the Hα region, during two observing campaigns at Catania Observatory. During the first campaign, 1988 June 22 – 29, 135 spectra were collected, while 12 spectra were obtained during the second campaign which spanned from June 2nd to June 12th 1989.

We have recorded the spectra of the two stars composing the visual binary (σ_1 and σ_2 CrB) on the same frame by placing the spectrograph slit along the line connecting the two stars. This enabled us to obtain a light curve in the red band (λ6410 – 6590 Å), using σ_1 CrB as comparison star. The light curve exhibits changes in the amplitude and in the phase of minimum light between the two observing seasons. The equivalent width of the Hα emission core has been evaluated using the spectrum synthesis method. Hα emission from both components of the inner system is detected in the spectra near quadrature, but it is stronger in the cooler G0 V star. The Hα equivalent width shows low-amplitude modulation in both years which seems to be anti-correlated with the simultaneous light curve.

Comparing our results of the 1988 campaign with the contemporaneous X-ray, UV, and Radio measurements reported by Stern et al. (1992) we show that the Mg II flux of the cooler component is anti-correlated with our light curve, and a similar behaviour is displayed by the Ly-α flux reported by Hannikainen et al. (1990).

Key words: stars: chromospheres – stars: activity – stars: binaries: close – object: σ_2 CrB; TZ CrB

1. Introduction

σ CrB, is a triple system composed by a single star (σ_1 CrB), and a RS CVn like binary (σ_2 CrB = TZ CrB). These two subsystems have an orbital period of 1000 years and a separation of 140 AU which at the distance of 21 pc leads to a 6.6 arcsec apparent separation. The fainter component (σ_1 CrB) is classified as G1 V (Hoffleit 1982) with an effective temperature of T = 5970^{o}K.

The inner binary σ_2 CrB is composed by an F6 and a G0 dwarfs. The orbital period of this close binary is equal to 1.14 days and the separation is 5.9 $R_\odot$. The system inclination is estimated to be 28^o and the orbital eccentricity is found to be rather small (e = 0.022) and consequently the orbit can be considered as circular (Bakos, 1984).

The system σ_2 CrB is well known for his high magnetic activity level (Bopp 1984), and, because of similarities to X-ray, UV, optical and radio properties, is classified as an RS CVn-like binary, though both components are dwarf stars (according to the strict definition, an RS CVn system must have at least a subgiant component, Hall 1976, Fekel et al. 1986). Furthermore the two components are solar-like stars (Giménez et al. 1986) which rotate much faster than the Sun; this characteristics make σ_2 CrB a very attractive system because it would represent a useful test on the evolution of the Sun's activity with rotation.

Photometric studies made by Giménez et al. (1986) and Strassmeier et al. (1989) indicate a photospheric activity present on one or both stars. Strong Ca II H and K emissions coming from both components have been reported by Bakos (1984), Fernández-Figueroa et al. (1986) and Strassmeier et al. (1990). A notable chromospheric emission from both components is also evident from the Mg II h and k emission profiles (Stern et al. 1992).

Hα excess emissions from both components have been reported by Barden (1985) and Montes et al. (1995a). Eker et al. (1995) show high resolution ($\Delta\lambda$ = 0.24 Å) profile filled-in with variable emission. Moreover, flaring activity has been detected through X-ray and radio observations (Van den Oord et al. 1988, Stern et al. 1992).

Here we present spectrophotometric observation of σ_2 CrB in the Hα region obtained during the coordinated Ginga, IUE and VLA observations in June 1988 (Stern et al. 1992) and additional data obtained in June 1989. Differential photometry in the 6410 - 6590 Å interval with respect to the σ_1 CrB visual

Send offprint requests to: S. Catalano

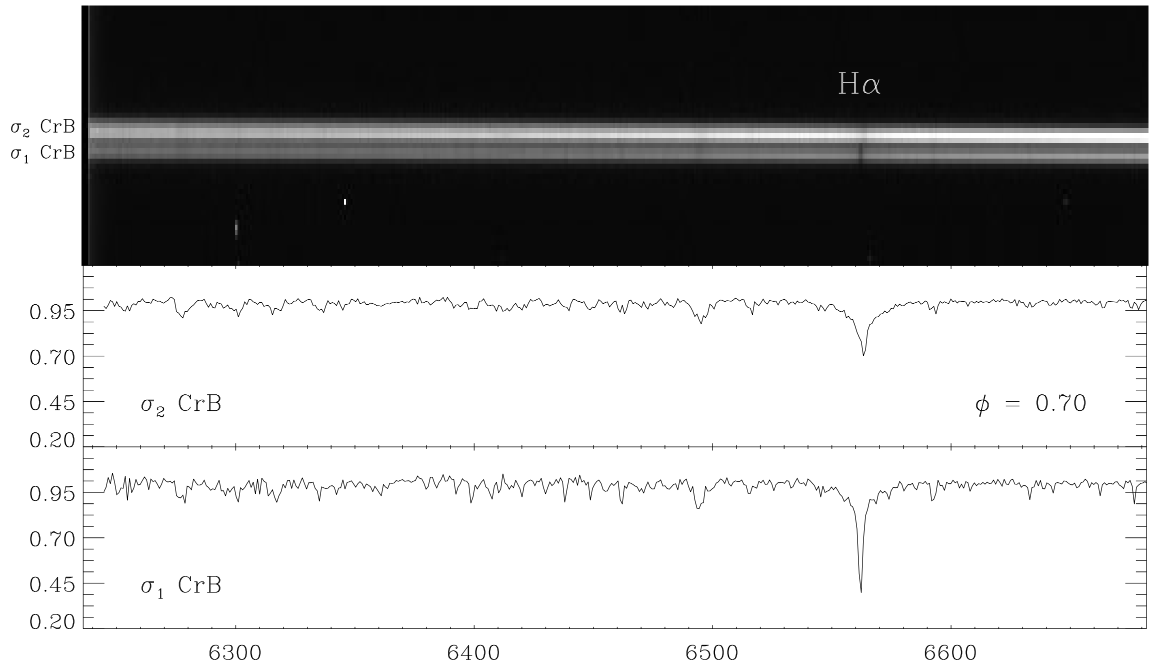

Fig. 1. The upper panel shows a portion of a CCD spectrum image. The two lower panels display the corresponding normalized spectra of σ_2 CrB and σ_1 CrB.

component is analysed in comparison with the Hα emission EW measured on the same spectra. The results of our photometry and Hα emission are discussed in relation to the X-ray and UV observations by Hannikainen et al. (1990) and Stern et al. (1992).

2. Observations and data reduction

2.1. Data acquisition

The observations have been carried out with the Echelle spectrograph feeded by the 91-cm telescope of the Catania Astrophysical Observatory at the *M.G. Fracastoro* station in Serra La Nave (Mount Etna) from 22 to 29 June 1988 and from 2 to 12 June 1989. In total, 135 and 12 spectra were obtained in 1988 and 1989 respectively. The 1988 observations have been performed in connection with the coordinated GINGA, IUE and VLA observations, at X-ray, UV and radio wavelengths (Stern et al. 1992). We used the spectrograph in the low-dispersion configuration with the 1200 lines/mm echellette grating, which gives a linear dispersion of 40 Å/mm. The spectra were recorded on a 385 × 576 E.E.V. CCD of 22 × 22 μm pixel size (Bonanno & Di Benedetto 1990) which yields a pixel-to-pixel resolution of 0.89 Å. We used a slit width of 150 μm, that corresponds to a projected half-width spectral element of 0.9 Å on the spectrograph focal plane. The wavelength range covered by the 512 pixels used on the CCD's longer side is about 450 Å (from about 6250 Å to 6700 Å). The direction of wavelength dispersion runs nearly parallel to the columns of the detector, with a misalignment smaller than 0.3 pixels between the beginning and the end of the spectrum.

Since the spectrograph can be rotated around the telescope optical axis, we orientated the spectrograph slit along the line connecting the two components of the visual binary and then we were able to record the spectra of σ_1 CrB and σ_2 CrB on the same frame. So each image includes two strips very close to each other representing the spectra of σ_1 and σ_2 Coronae Borealis. In Fig. 1 a portion of one image containing the two spectra is shown together with the extracted, wavelength-calibrated and continuum-normalized spectra of σ_2 and σ_1 CrB, respectively (lower panel).

Since the two stars are presently separated by 6.6 arcsec on the sky, their projected separation is about 4 pixels, therefore, in normal seeing conditions (typically 2 arcsec), the spectra appear fairly well separated. Actually, in one night only, we had a so bad seeing, that the two spectra could not be separated because heavily blended. These data were not included in our analysis.

An example of the brightness distribution along the slit (i.e. across the dispersion) is shown in Fig. 2, in which the sum of 150 detector's rows is plotted. The two gaussians fitted to the brightness (seeing) profile have been used to separate the light of the two stars in order to determine the differential magnitude, as will be discussed later.

The spectra have been acquired with exposure times between 60 and 100 seconds for the observations made in 1988, and 120 seconds for those made in 1989. Thus a signal-to-noise ratio (S/N) of about 100 (a little bit higher for 1989) was reached at the Hα continuum of the brighter star. The fainter star spectra have a slightly lower S/N.

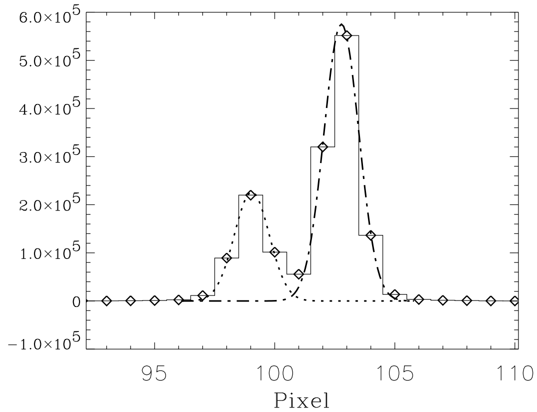

Fig. 2. Brightness distribution across the slit obtained summing 150 rows of the detector at a mean wavelength of 6500 Å. The two gaussian fits to the σ_1 and σ_2 seeing profiles have enabled us to perform differential photometry of σ_2 CrB, using σ_1 as comparison star.

2.2. Reduction and evaluation of the Hα equivalent width

All the spectra have been extracted from the CCD images following a standard reduction procedure that consists in background subtraction, division by a flat field spectrum given by a halogen lamp, extraction of the spectra by summing up the pixel values, at each wavelength, of all the columns containing the highest stellar signal (generally 3 pixels for each star), subtraction of the sky spectrum from the stellar one, and wavelength calibration (using the emission lines of a Cesium lamp). The attempt to extract the spectra of σ_1 and σ_2 CrB by fitting two gaussians to each detector row (i.e. at each wavelength), tested on several images, led to spectra in good agreement with those extracted by summing up the 3 central uncontaminated columns, but with a worse S/N.

The spectra, extracted as described before, have been normalized to the continuum adopting a polynomial fit to spectral windows apparently free from absorption lines. An example of the extracted and normalized spectra is shown in Fig. 1.

To define the net Hα emission of the active star, we have subtracted a synthetic spectrum per each observed one (see Frasca & Catalano 1994). The synthetic spectrum has been built up by the weighted sum of two spectra of inactive stars mimicking the two components of σ_2 CrB. The spectra of the two reference stars have been taken in similar instrumental conditions to those of the target star. The primary star spectrum (type F6 V) has been simulated by an average spectrum of HR 8536 (F5 IV), while the secondary (G0 V) has been reproduced by an average spectrum of σ_1 CrB (G1 V).

Fernández-Figueroa et al. (1994) have presented Ca II H & K profiles of σ_2 CrB showing clear emission cores. Montes et al. (1995b) checked the emission on σ_1 CrB spectra and found that the core of the Ca II lines is marginally filled - in with emission which would indicate a very low activity degree in this stars, i.e. much lower than σ_2 CrB and completely undetectable in the Hα line. In order to test a possible activity, we compared each σ_1 CrB spectrum with the average of 15 spectra taken on 23 June 1988. No apparent residual emission is visible at Hα in any difference spectrum (single spectrum minus average). Integrations over the line width lead to negligible mean residual $EW_{H\alpha} = 4.21\ 10^{-3}$ Å with a standard deviation $\sigma = 4.48\ 10^{-2}$ which is well within the accuracy our spectra. Therefore σ_1 CrB can be reliably used as a reference non active star at Hα.

The relative luminosity of the two components given by Barden (1985), 55% and 45% for the hotter and the cooler respectively, have been used in weighting the spectra of the reference stars. The relative Doppler shifts due to the orbital motion of the two components have been taken into account to define the synthetic spectra using the spectroscopic ephemeris given by Bakos (1984). Since the $v \sin i$ of the hotter and cooler component, 26 km s^{-1} and 25 km s^{-1} respectively, (Barden 1985) are smaller than the instrumental resolution (0.89 Å which corresponds to 41 km s^{-1}) no rotational broadening has been applied to the spectra of the reference stars.

In Fig. 3, we show, on the left, some extracted (thick line) and synthetized (dotted line) spectra at different phases and on the right side the difference spectra. Excess emission is evident in all of them while the difference in the other spectral regions is within the expected noise, indicating a correct reproduction of the photospheric spectrum by the synthetic one.

Due to the low resolution of our spectra, it is difficult to separate the emission contributions of the F6 and G0 components, but near the quadratures, where it seems that some emission could arise also from the primary component (Fig. 3). However for our analysis, the net equivalent widths ($W_{H\alpha}$) have been determined by integrating over all the residual emission profile (see Fig. 3), therefore including the emission of both stars.

We estimate the error in the equivalent width ($\Delta W_{H\alpha}$) as the product of the internal error in a single spectral element and the number of elements in the integration range, evaluating the internal error in the spectra as the standard deviation of the residual spectrum values in two continuum regions near Hα.

2.3. Photometry

The opportunity to record the spectra of σ_1 CrB and σ_2 CrB on the same frame has enabled us to obtain a differential photometry simultaneously with the Hα data. To ensure that a constant fraction of light could be collected from both stars, the orientation of the entrance slit was never changed during each of the two observing runs.

In order to separate the light of the two stars we have fitted two gaussians to the projected brightness distribution perpendicularly to the dispersion, which represents a cross section of the seeing disks of the two stars along the slit. Since the two profiles are partially overlapped (see Fig. 2) and we have only 9 – 10 pixels to define the brightness profile, 150 rows per each image from λ6410 Å to λ6590 Å have been summed up to increase the signal-to-noise ratio, and therefore the accuracy of the magnitude difference. The magnitude difference can be considered to be close to the Johnson R magnitudes (λ_{eq} = 7000 Å).

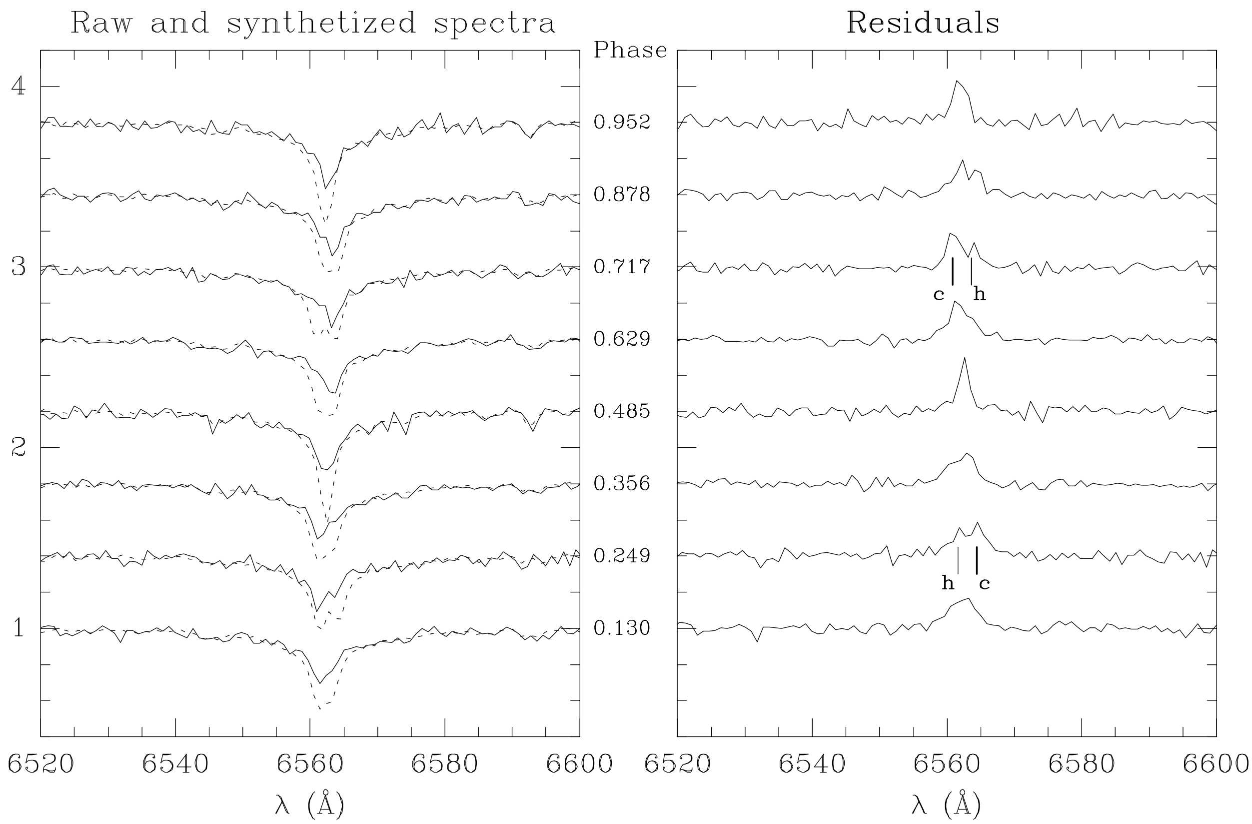

Fig. 3. Sample of σ_2 CrB 1988 observations at differents phases. Raw (thick line) and synthetized spectra (dotted line): left panel. Residuals obtained from the subtraction of the synthetic spectrum (right panel). Emission from the hot and cool components are indicated by h and c.

The sky signal and the electronic background have been subtracted from the brightness profile, when making the fit. The fitting procedure was performed for all the images in two phases. Firstly, we assumed the center, the maximum value and the sigma of the two gaussians as free parameters; then the fit has been re-done fixing the gaussian sigma of the fainter component equal to that found for the brighter one, which is better determined due to its higher signal. We have therefore used only four free parameters and the magnitude difference have been derived from the integral of the two fitted gaussians. This magnitude differences are much noisier than expected from the intrinsic S/N ratio. The analysis for variability with a period of about $0^{\rm d}.1$ claimed by Skillman & Hall (1978) gives no evidence for such periodicity, so the excess noise may be due to the seeing effect and the non uniform tracking of the telescope.

Therefore, in order to improve the magnitude values, the data have been averaged at one hour bins. In 1988, 135 spectra have been acquired, with an average of 15 – 25 spectra per night, so that we have a good phase coverage of the light curve with a final photometric accuracy of about $0^m.02$. In 1989 only two spectra per night were taken, but at higher signal-to-noise ratio. The two magnitude values in each night generally agree within $0^m.02$. Nightly means have been made also in that case, with a consequent poorer phase coverage.

3. Results

3.1. Light curve

Average values for the 1988 and 1989 campaign are listed in Table 1 and plotted in Fig. 4 versus orbital phases, computed according to the spectroscopic ephemeris given by Bakos (1984) with the corrected zero epoch given by Giménez et al. (1986), for the superior conjunction (hotter star behind) : J.D. = 2 423 869.390 + 1.1397912 E.

The light curve appears to have experienced significant changes, the amplitude was about $0^{\rm m}.08$ in 1988 and $0^{\rm m}.12$ in 1989, while the minimum light occurred at $\phi \simeq 0.2$ in 1988, and at $\phi \simeq 0.5$ in 1989. Also the mean level is different in the two seasons ($-1^m.05$ in 1988, and $-1^m.13$ in 1989) but this may not be necessarily indicative of an activity variation (decreasing level of spottedness) because the orientation of the entrance slit of the spectrograph has been changed between the two runs and, as we have experimented, changes in the alignment produce significant differences in the light fraction of the two stars collected by the slit. Unfortunately, we have no valid test for estimating to what accuracy the slit was re-aligned. However, since all the values displayed for each observing run were obtained in the same configuration, the information on the wave amplitude and

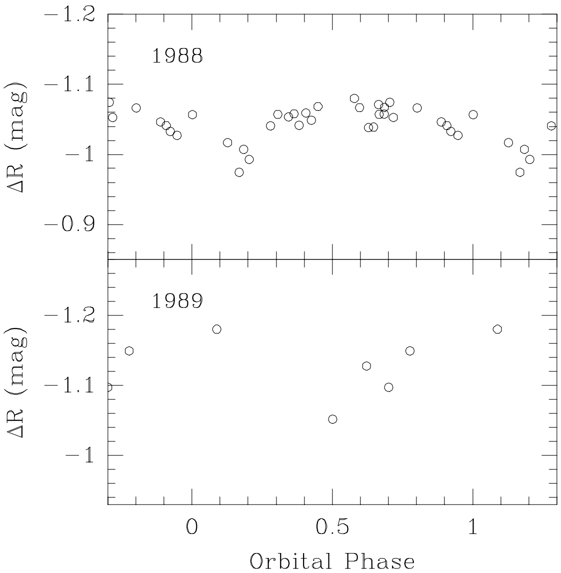

Fig. 4. σ_2 CrB light curve for 1988 and 1989. The point represented are magnitudes averaged on one hour, computed as described in Section 2.3. The typical error is about $0^m.02$.

on the phases of minimum and maximum, should be considered of high reliability.

Skillman & Hall (1978) reported two types of V light variability : the first with the orbital period and an amplitude of ~ 0.05 mag. and the other with the same amplitude but with a much shorter period (0.1 days) that was ascribed by the authors to δ scuti-type variations. Bakos (1984) did not found the 0.1 days variation. His data display nearly constant values in almost all seasons, with the exception of those from J.D. 2444350 to J.D. 2444464 which show a wave of about $0^m.15$ amplitude and the light minimum at phase ∼0.45. Giménez et al. (1986) found a clear cyclic variation with the orbital period and an amplitude of only $0^m.012$ in the Strömgren **y** filter that, corrected for the contribution of σ_1 CrB, included in the diaphragm, amount to $0^m.016$. Strassmeier et al. (1989) found a variation period very similar to the orbital one, and wave amplitudes ranging from $0^m.045$ (1984) to $0^m.055$ (1985). In 1985, the phase of minimum occured at $\sim 0^p.4$. These authors found also long term variations with a time scale of about 2 year.

As mentioned before, we did not find evidence for the 0.1 day variability which actually has been already rejected by Bakos (1984) and Giménez et al. (1986). The light curve amplitude we found is, on the average, larger than that found by the previous authors, with exception of Bakos (1984) observations between J.D. 2444350 and J.D. 2444464. The variability in the light curve amplitude and in the phase of minimum light is consistent with the previous results and is indicative of long term activity changes (cycle ?). The present largely inhomogeneous and scanty data do not allow us to look for cyclic periodicity.

Table 1. Photometric data

HJD (+2440000)	Phase	ΔR (mag)	Error (rms)	Number of points
7335.5562	0.1271	-1.017	± 0.017	2
7336.4238	0.8882	-1.047	0.016	4
7336.4468	0.9083	-1.041	0.030	4
7336.4629	0.9227	-1.033	0.031	2
7336.4907	0.9473	-1.027	0.024	3
7336.5527	0.0017	-1.057	——	1
7337.4653	0.8021	-1.066	0.035	3
7338.4487	0.6647	-1.071	0.009	4
7338.4727	0.6858	-1.067	0.022	6
7338.4946	0.7052	-1.075	0.004	2
7338.5088	0.7175	-1.053	——	1
7339.4902	0.5784	-1.080	0.031	4
7339.5117	0.5975	-1.067	0.024	4
7339.5474	0.6289	-1.038	0.047	7
7339.5688	0.6475	-1.039	0.033	6
7339.5908	0.6670	-1.057	0.034	5
7339.6113	0.6849	-1.058	——	1
7340.4336	0.4063	-1.059	0.042	6
7340.4551	0.4251	-1.049	0.040	6
7340.4819	0.4488	-1.068	0.020	6
7341.4292	0.2801	-1.041	0.036	4
7341.4590	0.3061	-1.057	0.011	5
7341.5029	0.3445	-1.054	0.018	8
7341.5244	0.3635	-1.058	0.004	7
7341.5454	0.3819	-1.042	0.022	5
7342.4419	0.1685	-0.974	0.023	7
7342.4600	0.1844	-1.007	0.028	5
7342.4819	0.2037	-0.993	0.032	6
7680.5130	0.7764	-1.149	——	1
7681.4771	0.6221	-1.128	± 0.010	2
7686.5678	0.0885	-1.180	0.004	2
7689.5450	0.7005	-1.097	0.019	2
7690.4570	0.5007	-1.052	0.015	2

3.2. Hα emission

The difference spectra in Fig. 3, show that the Hα line of both components is filled-in by emission and the filling is more pronounced in the cooler component, as already found by Barden (1985), and it is apparent in other chromospheric diagnostics like Ca II and Mg II (Bakos 1984, Fernández-Figueroa et al. 1986, Strassmeier et al. 1990, Stern et al. 1992).

Since it is difficult to separate the emission contributions of the two stars to analyse the Hα emission behaviour of the system, we have integrated all the residual emission profile produced by both components. In Fig. 5, we display the Hα emission equivalent width $W_{H\alpha}$ versus phase, using nightly means separately for 1988 (higher panel) and 1989 (lower panel) sea-

Table 2. Hα data

HJD (+2440000)	Phase	$W_{H\alpha}$ (Å)	$\Delta W_{H\alpha}$ (Å)	Number of points
7335.5562	0.1271	0.82	± 0.07	2
7336.4517	0.9128	0.80	0.05	13
7337.4653	0.8021	0.78	0.15	3
7338.4712	0.6848	0.79	0.06	13
7339.5479	0.6294	0.85	0.05	27
7340.4634	0.4326	0.78	0.07	17
7341.4937	0.3363	0.85	0.04	30
7342.4824	0.2040	0.85	0.12	27
7680.5169	0.7793	0.77	± 0.12	2
7681.4771	0.6222	0.79	0.20	2
7684.5617	0.3224	0.86	0.11	2
7686.5678	0.0885	0.75	0.12	2
7689.5450	0.7005	0.79	0.10	2
7690.4570	0.5007	0.86	0.12	2

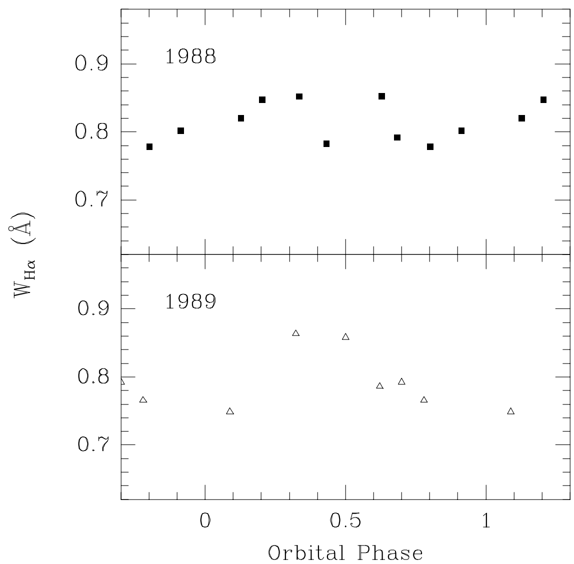

Fig. 5. Hα equivalent width plotted against orbital phase. Upper panel 1988 data, and lower panel 1989 data.

son. The $W_{H\alpha}$ average value is about 0.8 Å in both years, and the rms errors on each average point range from 0.05 to 0.1 Å. Average equivalent width data are listed in Table 2.

The rotational modulation is apparent in both years, with an amplitude of about 0.07 Å and 0.1 Å in 1988 and 1989 respectively. The maximum emission seems to occurs around phase $0^p.25$ in 1988 and at phase $0^p.4$ in 1989. The changes in the amplitude and shape of the Hα curve seem to be consistent with a slight increase in the activity in 1989, also displayed by the light curve. The light minimum in 1988 occurred significantly earlier than the Hα maximum, while in 1989, both seem to occur around the same phase ($0^p.4 - 0^p.5$) reinforcing the spatial association of spots and plages seen for many other systems (see Catalano et al. 1996). Although, the shift of the Hα maximum between 1988 and 1989 is smaller than the shift in the light curve minimum, a significant spatial association of photospheric spots and chromospheric plage is suggested to persist for more than one year. However, as we will discuss in more detail in the next paragraph, the changes in the Hα modulation may result from uncorrelated changes in the plage distribution on the surface of both stars, while the spots may be primarly associated to the cooler component.

Montes et al. (1995a), from one spectrum at 0.5 Å resolution, taken in July 1989, measured an emission $EW_{H\alpha}$ of 0.635 Å. Eker et al. (1995) displays five high resolution (0.24 Å) spectra of moderate S/N (80) which show variable profiles. They do not give any information about the EW, but notice the stronger emission filling in the cooler G0 V component. Barden (1985) gives the $W_{H\alpha}$ values deduced from 0.6 Å resolution spectra, for both components and found 0.164 Å for the hotter and 0.377 Å for the cooler. Considering the continuum contributions of 0.55 and 0.45 for the hotter and the cooler component respectively, a ratio of about 2.8 between the corrected net equivalent width of the cooler and hotter component is derived. Although is difficult to separate the emission contribution of the two stars, we have estimated an emission ratio of 2.9 ±0.3, in good agreement with the Barden's results (1985) from the net 1989 spectra (in which year S/N is better) taken near the two quadratures. For comparison, the flux ratios in the Mg II lines is on average about 1.1, ranging from ∼0.9 to ∼ 1.3 (Stern et al. 1992), and in the Ca II lines is from 1.1 to 1.8 according to Bakos, (1984). The higher EW ratio in the Hα emission can be ascribed to the double origin of the line (photoionization + collisions) which makes the line formation of the hotter component more controlled by the photospheric continuum. This leads to a depopulation of the level three hydrogen atoms and therefore producing lower sensivity to the chromospheric temperature rise, with respect to that produced on the cooler component.

4. Discussion

Our 1988 Hα spectra have been acquired concurrently with IUE (at both short and long wavelength), Ginga satellite (X-ray) and VLA microwave observations presented by Stern et al. (1992). They observed flaring activity in X ray, the strongest event being detected also in the microwave region and in the TR UV lines (C IV and Ly-α). On June 28th starting at 12 U.T., the LAC count-rate rose from about 3 to 8 counts sec^{-1}, the microwave flux at 6 cm from the quiescent level of ∼ 5 mJy increased to ∼ 30 mJy. Smaller enhancements were observed in C IV, Si IV, lines and Ly-α, while no intensification was observed in the Mg II ultraviolet doublet. The flare duration in the X-ray band was about 2 – 4 hours. Our Hα observations on June, the 28th started at 22 U.T., and so all the spectra were acquired after the

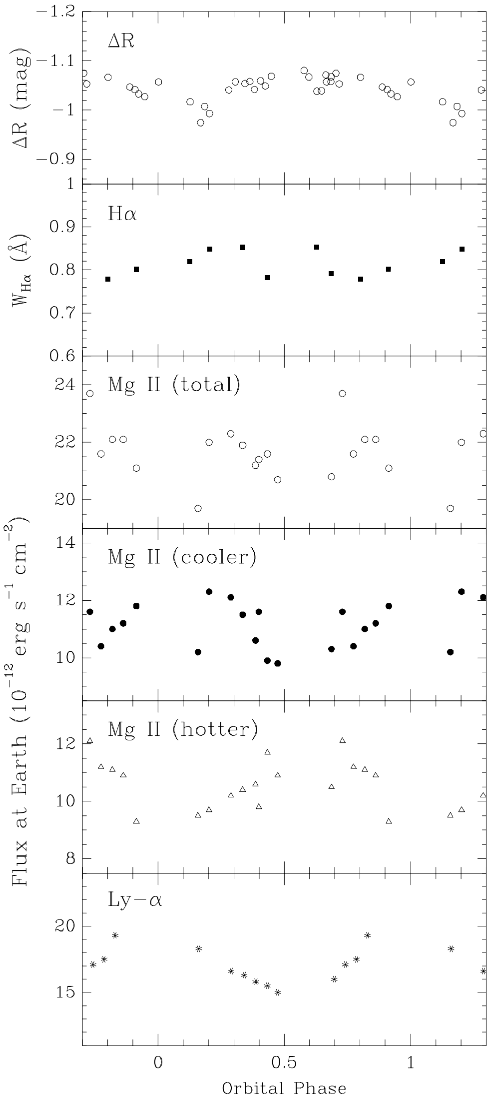

Fig. 6. From top to bottom we present for the June 1988 season: light in the red continuum, Hα equivalent width, Mg II flux at Earth (total, from cooler component only, and from hotter component only), and Ly-α flux, plotted against orbital phase. The Mg II and Ly-α data have been taken from Stern et al. (1992) and from Hannikainen et al. (1990).

flare occurrence, indeed we have no trace of Hα enhancement in any spectrum. Another X-ray burst of similar intensity also observed on June 28 at 01 - 02 UT was not accompanied neither by radio flux nor by UV lines intensification (Stern et al. 1992). Our Hα spectra, taken simultaneously with this event do not show any appreciable evidence of flare enhancement.

Stern et al. (1992) claim for a possible periodic variation in X ray with a period of $0^d.40 - 0^d.44$. Hannikainen et al. (1990) in a previous analysis of the same Ginga and IUE data indicated a possible rotational modulation of the UV line flux. In order to investigate the concurrent modulation of chromospheric and photospheric diagnostics, we have re-examined the data presented by Stern et al. (1992) and Hannikainen et al. (1990) together with our simultaneous photometry and Hα spectra. In Fig. 6 from top to bottom, our light and Hα curve, the Mg II combined flux at the earth, the flux from the cooler and hotter component, taken from Stern et al. (1992) and the Ly-α flux from Hannikainen et al. (1990) are plotted against orbital phase. We have excluded the Ly-α fluxes taken just before and during the June 28 flare.

The total Mg II h + k flux (cooler and hotter component) shows very small variations, but the fluxes of the cooler and the hotter component appear separately modulated with the orbital period. The Mg II flux data of the hotter star appear to be more or less anti-correlated with that of the cooler component, but with a slightly lower amplitude and more spread, giving rise to a total flux with very small variations, which resembles our Hα curve. From these evidences we can argue that the small variations observed in Hα are possibly due to a combination of the effects produced by chromospheric inhomogeneities on both stars as displayed by the Mg II. The combined Ly-α flux shows a modulation practically in phase with the Mg II flux of the cooler component, the maximum occuring at phase $0^p.0$ and $0^p.1$ for Mg II and Ly-α curves respectively. This seems to be a clear indication that the Ly-α emission is essentially originated in the chromosphere of the cooler component.

Moreover, it is interesting to note that the Mg II flux of the cooler component, as well as the Ly-α flux, is anticorrelated with our light curve. This anti-correlation would suggest that the light variation mainly arises from photospheric spots on the secondary component, implying a close spatial association of photospheric and chromospheric active regions in that star which could be considered as the more active in the system.

5. Conclusion

From accurate contemporaneous differential spectrophotometry, we have shown that TZ CrB presents anticorrelated photospheric and chromospheric (Hα) variations, supporting the close spatial association between spots and plages already found in other active stars (e.g. Bopp & Talcott 1978, Ramsey & Nation 1984, Catalano & Frasca 1994 and Catalano et al. 1996). Moreover, the comparison of the light curves with detailed Mg II emission modulation of the two components in the system enabled us to suggest that the photometric variability appears to be mainly due to dark spots on the secondary star. Although the more apparent emission of the secondary star in Hα may be the result of the emission component formation process (the lower photospheric temperature favoring the collisional excitation in this star, more than in the hotter one) the Mg II and Ly-α data (Stern et al.1992, Hannikainen et al.1990) push for a stronger activity on the secondary.

The flare detected by Stern et al. (1992) in X-ray, Radio and U.V. on June 28 at 12 U.T., is not present in our Hα measures. Since our closest observations started at 22 U.T., this means either that there is no Hα emission counter part for this event, or that the event has, also in Hα, a time scale shorter than 10 hours, contrary to many Hα events in RS CVn systems which have time scale longer than 24 hours (e.g. Catalano 1996). The lack of Hα enhancement during the other marginal X-ray flare detected by

Ginga earlier in the same day, at 01 : U.T., does suggest that chromospheric flares are barely excited in this system.

Acknowledgements. This work has been supported by the Italian *Ministero dell'Università e della Ricerca Scientifica e Tecnologica,* the *Gruppo Nazionale di Astronomia* of the CNR and by the *Regione Sicilia* which are gratefully acknowledged. D.M. also acknowledges the Italian *Ministero degli Affari Esteri* for a grant in the *Lavoisier* convention part with the French Government, and wants to express his gratitude to the Catania Astrophysical Observatory for the support received during his stay in Catania and to all the staff for the warm reception.

References

Bakos G.A., 1984, AJ 89, 1740
Barden S.C.,1985, ApJ 295, 162
Bonanno G. & Di Benedetto R., 1990, PASP 102, 835
Bopp B.W., 1984, ApJS 54, 387
Bopp B.W. & Talcott J.C., 1978 AJ 83, 1517
Catalano S.,1996 in *Magnetodynamic Phenomena in the Solar Atmosphere, Prototypes of Stellar Magnetic Activity*, I.A.U. Coll. 153, Y. Uchida, T. Kosugi and H.S. Hudson (eds.), Kluwer Ac. Publ., Dordrecht (in press)
Catalano S. & Frasca A., 1994, A&A 287, 575
Catalano S., Rodonò M., Frasca A. and Cutispoto G., 1996 in *Stellar Surface Structure*, I.A.U. Symp. 176, K.G. Strassmeier and J.L. Linsky (eds.), Kluwer Ac. Publ., Dordrecht, p. 403
Eker Z., Hall D.S., Anderson C.M., 1995, ApJS 96, 581
Fekel F.C., Moffet T.J., Henry G.W., 1986, ApJS 60, 551
Fernández-Figueroa M.J., Montes D., De Castro E., Cornide M., 1994, ApJS 90, 433
Fernández-Figueroa M.J., Montesinos B., De Castro E., Rego M., Giménez A., Reglero V., 1986, A&A 169, 219
Frasca A., Catalano S., 1994, A&A 284, 883
Giménez A., Ballester J.L., Reglero V., 1986, AJ 92, 131
Hall D.S., 1976; In: *Multiple periodic variable stars*, I.A.U Coll. 29, W.S. Fitch (ed.), D. Reidel Publ. Co., p. 287
Hannikainen D., Vilhu O., Huovelin J., Stern R.A., 1990, ESA SP-310: *Evolution in Astrophysics: IUE Astronomy in the Era of New Space Missions*, p. 387
Hoffleit 1982 *The Bright Stars Catalog* 4^{th} edition
Montes D., Fernández-Figueroa M.J., De Castro E., Cornide M., 1995a, A&A 294, 165
Montes D., De Castro E., Fernández-Figueroa M.J., Cornide M., 1995b, A&AS 114, 287
Ramsey L.W. & Nation H.L., 1984 AJ 89, 115
Skillman & Hall, 1978, *Inf. Bull. Var. Stars* 1529
Stern R.A., Uchida Y., Walter F., Vilhu O. et al. 1992, ApJ 391, 760
Strassmeier K.G., Fekel F.C., Bopp B.W., et al. 1990, ApJS 72, 191
Strassmeier K.G., Hall D.S., Boyd L.J., Genet R.M., 1989, ApJS 69, 141
Van den Oord G.H.J., Mewe R., Brinkman A.C., 1988, A&A 205, 181

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.