PHOTOMETRIC AND Hα MODULATION ON ACTIVE STARS

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Abstract. Systematic photometric monitoring of active RS CVn binaries carried out at Catania with the automatic telescope APT-80, is being complemented with Hα low- and high-resolution spectroscopy. The relationship between photospheric and chromospheric activity is investigated in order to shed light into the complex three-dimensional structure of surface activity. Preliminary results on the photometric and Hα monitoring of the active binaries, UX Ari, RS CVn, BM CVn, HK Lac, IM Peg, V 711 Tau, and EI Eri, are here reported.

1. Introduction

Periodic or quasi-periodic low-amplitude continuum and emission line flux variations are observed in late-type active stars. The flux variations appear as distortion waves, which can vary in shape and amplitude over a few months or years. These variations are attributed to unevenly distributed surface inhomogeneities, whose visibility is modulated by stellar rotation. Solar analogues (sunspots, plages, flares and cycles) are usually invoked to explain stellar disk integrated observations. However, in order to understand the similarity and differences with respect to the Sun it is of great importance to know the geometric distribution of activity phenomena on stars, and to study the correlation between the structures observed at different heights.

An outstanding result in this area of study is offered by the evident anticorrelation seen between transition region (TR) emission lines fluxes and visible light in II Peg (Rodonò et al. 1987). Measurements at light minimum (maximum spottedness) have shown five to ten times increase

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in TR line intensity over those at light maximum. The correlation between starspot position and enhanced chromospheric emission is more convincing, as demonstrated by Mg II hk (Rodonò et al. 1987, Doyle et al. 1989, Byrne et al. 1992) and Hα line observations (Bopp and Talcott 1978, Ramsey and Nation 1984).

Taking advantage of the photometric and spectrographic instrumentation available at Catania Observatory (an automated photometric telescope APT-80 and an echelle spectrograph feed by the 91 cm telescope through an optical fiber link), we have undertaken systematic and coordinated photometric and Hα monitoring of active RS CVn binaries. The aim of these observations is the study of the degree of correlation between photospheric and chromospheric active regions, their time evolution and possible dependence on spectral type or mass of the active star.

Here we present preliminary results on recent observations. In order to investigate the degree of spatial correlation, we have made simple geometrical solution of the V and Hα light curves obtained during the course of the same observational season.

2. Observations

Both spectrographic and photometric observations were obtained at the Serra La Nave Station of Catania Astrophysical Observatory. The active binaries, and details on the observation seasons, here discussed, are listed in Table 1.

2.1. THE SPECTROSCOPY

Spectroscopic Hα observations were performed using the REOSC echelle spectrograph both in the low and high dispersion mode. The low-dispersion configuration consists only of the 1200 lines/mm echellette grating which gives a spectral resolution of 1.7 Å. The high resolution is given by the cross-dispersion configuration, which yields a resolution of about 0.46 Å. The spectrograph is connected to the 91 cm telescope through an optical fiber link (UV-NIR fiber, 200μm core diameter, 14 m length) described by Sanfilippo (1993). The spectra were recorded on a CCD camera with a 385$\times$576 pixel chip from the E.E.V., pixel-size 22$\times$22 μm (Bonanno & Di Benedetto 1990). On the average a signal-to-noise ratio (S/N) of about 100–150 was reached at the Hα continuum.

In addition to active stars, we have observed some non-active (or much less active) stars with spectral type and luminosity class similar (or equal) to that of the primary and secondary stars of program systems. These spectra were used to define the reference Hα absorption profile of non-active stars. The Hα emission equivalent width $W_{\mathrm{H}\alpha}$ has been measured by

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TABLE 1. Properties of the observed stars

System	Sp. Type P/S	P_{orb} (*days*)	i°	Year	Sp. Resolution Å
UX Ari	G5V/K0IV	6.44	60	1989	1.7
" "				1994	0.46
HR 1099	G5IV/K1IV	2.84	33	1989	1.7
" "				1994	0.46
EI Eri	G5IV	1.95	46	1989	1.7
RS CVn	F4IV/G9IV	4.80	87	1989	1.7
BM CVn	K1III	20.62	—	1993	1.7
HK Lac	F1IV/K0III	24.42	70	1989,'90,'91,'93	1.7
" "				1994	0.46
IM Peg	K2III-II	24.65	—	1993	1.7

integrating the emission profile, after subtracting the synthetic spectrum (built up by a weighted sum of inactve-star spectra) from the spectra of the active binaries.

2.2. THE PHOTOMETRY

The main bulk of photometric observations has been performed with the 0.8-m Automated Photometric Telescope (APT-80), which feeds a single channel charge-integration photometer equipped with an uncooled Hamamatzu R1414 SbCs photomultiplier and standard UBV filters.

Each photometric measurement consists of 10–20s integration time in each filter, according to the star's magnitude. On the average a complete observation sequence for each program variable includes the following *f,ck,c,v,v,c,v,v,c,v,v,c,ck,f* measurements, where *f* indicates a nearby field star. The observations were corrected for atmospheric extinction and transformed into the UBV system by means of appropriate U B V standard stars, which were observed throughout the whole night.

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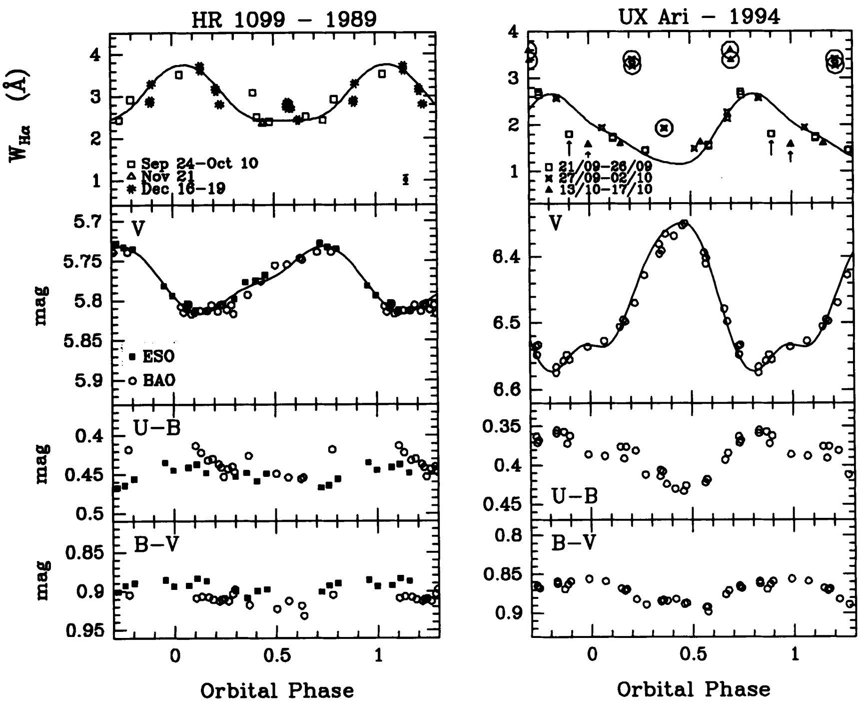

Figure 1. (Right) Hα emission curve, V and colour index light curves for HR 1099 in 1989. Photometric observations are taken from Zhai et al. (1994).
(Left) Data for UX Ari in 1994. The $W_{H\alpha}$ contaminated by flares (circles) and by excess absorption (arrows), have not been considered for the fit. Solid lines represent the plage and spot model fits to the data.

3. Results and discussion

Although evidence for anticorrelation between optical light curve and chromospheric or TR line flux has been often reported (Bopp and Talcott 1978, Ramsey and Nation 1984, Byrne et al. 1992) there are cases where strong Hα excess emission curves do not correlate with their corresponding optical light curves, e.g. HR 1099 (Fraquelli 1984), SZ Psc (Huenemorder & Ramsey 1984), HR 5110 (Eker & Doherty 1987).

In Figure 1 and 2 we present, as an example, some of the best observed Hα EW and photometric light curves. The common outstanding characteristic of the plot is the striking anticorrelation, in the sense that the Hα maximum is seen in correspondence of the V light minimum. However, the Hα variation amplitude does not seem to be correlated with the V light amplitude, neither in different stars nor in the same star. For example, the

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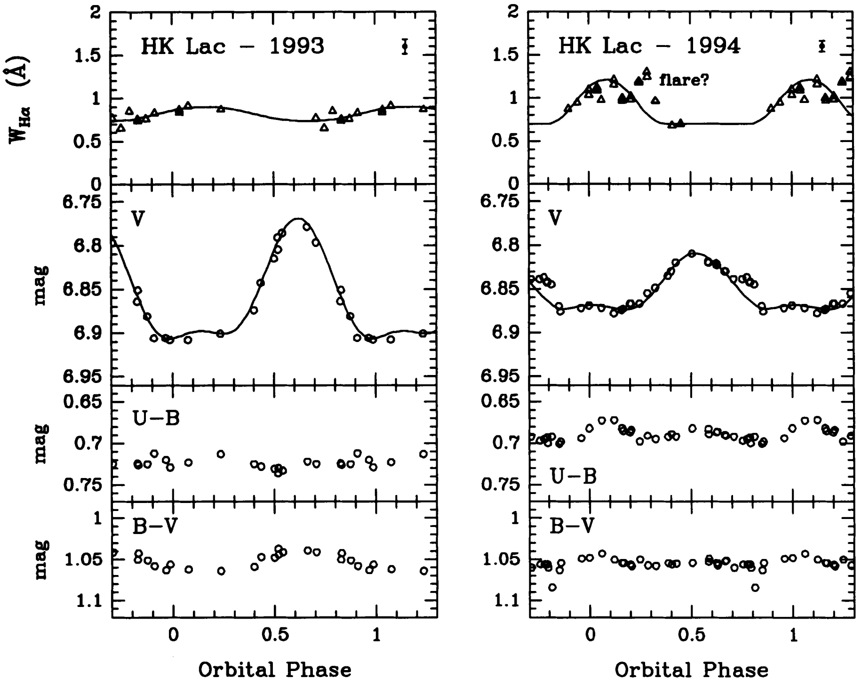

Figure 2. Hα emission curve, V and colour index light curves of HK Lac in 1993 (left) and in 1994 (right). The solid lines represent the plage and spot model fits to the data.

HR 1099 Hα enhancement in 1989 is 1.5 times and the corresponding light curve amplitude is $\Delta V = 0.^m14$, in UX Ari a 2.5 times Hα increase in 1994 is paired by a $\Delta V = 0.^m22$, while for HK Lac, to Hα enhancements of 1.2 and 1.7 times in 1993 and 1994, correspond $\Delta V = 0.^m13$ and $\Delta V = 0.^m07$, respectively. As often observed for RS CVn binaries, also our stars appear bluer at light minimum. Moreover, we should like to emphasize that the U–B curve, in several cases, closely follows the Hα curve shape; the UX Ari - 1994 data beeing the most striking case (Fig. 1). Because of the high opacity of the UV continuum, the UV light essentially originates in the chromosphere, and like the Hα line, it appears to be a good tracer of the chromospheric plages.

In order to investigate the structure of the outer atmosphere of active binaries, we have analysed our observations in the context of a solar-like spot model incorporating a cooler, darker active region, but also a region of enhanced Hα flux. For stars with well defined Hα and light curve a reconstruction of photospheric and the chromospheric surface structures has

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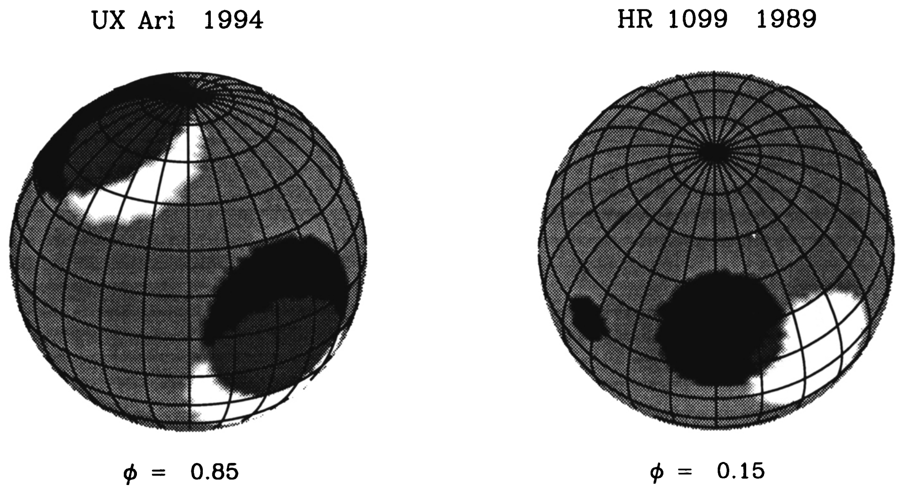

Figure 3. **Schematic representation of the photosphere and chromosphere of UX Ari and HR 1099 as reconstructed by the adopted spot and plage models.**

been made by means of the BINARY MAKER program (Bradstreet, 1993).

From the V light curves the usual parameters T_s/T_*, R_s, *lat, long* for the dark spot have been derived. In order to model Hα curves, bright spots have been considered, the emission flux ratio between plages and quiet chromosphere (F_{plage}/F_{chrom}), beeing assumed as a free parameter. This allows us to look for a geometrical solution where the size of the "bright spots" is only indicative and may give some evidence on the changes of configuration from year to year. These solutions should be essentially considered as geometrical solutions, with very low weight of the associated photometric and physical parameters. Obviously the more accurate parameter is the spot/plage longitude; the latitude and the size beeing only acceptable approximate values. Results of solutions for the better observed systems are summarized in Table 2, where the longitudes of the Hα plages ($l_{\rm Plage}$) and photospheric spots ($l_{\rm Spot}$), the average longitude of the two spots ($< l_{\rm Spot} >$) when only a plage was found and the longitude lag between spots and plages ($\Delta long$(S-P)) are listed. For systems with incomplete curves we give a rough estimate of the rotational phase of the minimum light and maximum Hα emission.

In Figure 3 are shown the photospheric/chromospheric maps of two systems, from which the spatial association of spots and plages is apparent.

Notwithstanding the mentioned uncertainties, the solutions of the photometric and Hα light curves, listed in Table 2, indicate a surprising co-

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TABLE 2. Parameters of the Hα plages and photospheric spots

System	Plage/Spot	$l_{\rm Plage}$	$l_{\rm Spot}$	$< l_{\rm Spot} >$	$\Delta long$(S-P)
UX Ari (1994)	1	275°	272°		-3°
" "	2	350°	36°		46°
HR 1099 (1989)	1	20°	52°	77°	57°
" "	2	—	103°		
" "	3	—	356.8°		
HK Lac (1989)	1	35°	61°		26°
" "	2	165°	208°		43°
HK Lac (1990/91)	1	35°	—		
HK Lac (1993)	1	60°	345°	50°	-10°
" "	2	—	116°		
HK Lac (1994)	1	30°	315°	32°	2°
" "	2	—	77°		

System	$\phi_{\rm maxH\alpha}$	$\phi_{\rm minV}$	$\Delta\phi$
UX Ari (1989)	$0^P.6$	$0^P.65$	$0^P.05$
EI Eri (1989)	$0^P.7$	$0^P.60$	$-0^P.10$
RS CVn (1989)	$0^P.25$	$0^P.05$	$-0^P.20$
BM CVn (1993)	$0^P.3?$	$0^P.60$	$0^P.30$
IM Peg (1993)	$0^P.8$	$1^P.00$	$0^P.20$

spatiality of the photospheric and chromospheric active regions. In some case the Hα curve leads to a solution with only one plage, while the photometric curve requires two spots. In such a case the plage turns out to be located between the two spots. In the Sun a systematic lag between chromospheric plages and photospheric activity complex is generally observed. In our solutions, with very few exceptions, we find a systematic lag of the Hα plage with respect to the spot by about 30–50°. No specific trend as a function of the rotational/orbital period or with the the spectral type is apparent. In the same star we sometimes find both positive and negative lags. However, on the basis of this limited data set we cannot discriminate whether the negative lag is due to the uncertainties in the solution or it is the result of a different time scale for the active area redistribution at photospheric and chromospheric level.

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4. Conclusion

We have clearly shown that close spatial association of chromospheric Hα plages to photospheric spots holds in short period (close) as well as in long period (relatively wide) active binaries. Moreover, in spite of the significant changes in the spot-plages configuration with time, the association is generally mantained. This suggest that dark stellar active regions (spots) and their associated enhanced Hα plages should be considered as a single entity, being spatially connected for considerable intervals of time, and parallelly evolving.

Although not definitely established, the chromospheric (Hα) plages seem to lag of about 30–50° with respect to the photospheric spots, like on the Sun. We hope that the systematic coordinated photospheric and chromospheric observations we intend to continue at Catania Observatory could give more clear insights into spatial and physical parameter correlation of photospheric and chromospheric active regions, also as a function of spectral type, orbital/rotational period, and activity cycles.

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