Spatially photospheric-coronal connections in SV Cam

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Abstract. The short period RS CVn binary SV Cam has been monitored at Konkoly Observatory since 1972. The collected homogeneous data allows us the study of the long-therm behaviour of the system. An important question in RS CVn studies is whether photospherically observed spots do correlate with observed phenomena at other layers of the stellar surface. To study spatial connections to other surface layers we needed additional spectroscopic (Doppler imaging) and X-ray observations. As result we could establish clear spatially existing correlations between photosphere and corona in the system.

1. Introduction

The eclipsing binary system SV Camelopardalis is one of the closest systems of the short period group of RS CVn systems. Basic data of the system are: $P_{orb} = P_{rot} = 0.5930$ day, $a = 4\,R_{\odot}$, $i = 90°$, $r_2/r_1 = 0.64$, $r_1 = 1.3\,R_{\odot}$, $T_1 = 5750$ K, $T_2 = 4500$ K, $d = 74$ pc.

SV Cam has been monitored at Konkoly Observatory for more than 25 years. Photoelectric UBV photometry was used to observe the system. The collected homogeneous data allowed us the study of the long-therm behaviour of this short period eclipsing binary. Unfortunately because of the complex behaviour of the system UBV photometry alone is not enough to study SV Cam.

We organized therefore simultaneous X-ray, spectroscopical and optical observations of SV Cam. An international team was formed to carry out this work. Members of the group were the following astronomers: A. Hempelmann (Astrophysikalisches Institut Potsdam, Germany), A.P. Hatzes (McDonald Observatory, The University of Texas at

Austin, U.S.A.), M. Kürster (Max-Planck-Institut für Extraterrestrische Physik, Garching, Germany) and L. Patkós (Konkoly Observatory of the Hungarian Academy of Sciences, Hungary). Our aim was to establish spatial connections between photosphere and corona in the system SV Cam.

2. Observations

We observed SV Cam photometrically between J.D. 2,449,254-57 with the 50 cm telescope at Piszkestető Mountain station of Konkoly Observatory. A second complete light curve was observed with the same instrument at J.D. 2,449,310-11.

In the X-ray spectral region 0.1-2.4 keV we observed SV Cam with the ROSAT PSPC. The total exposure time was 35.5 ksec. This total exposure time between J.D. 2,449,225-229 was distributed over eleven half an hour exposures and seven exposures lasting only a few minutes. Main part of these observations covered 3.5 consecutive binary orbits of SV Cam.

The spectroscopic observations were carried out at Sandiford Cassegrain Echelle spectrograph of the 2.1 m telescope of McDonald Observatory. Because of some technical difficulties our spectroscopic observations (J.D. 2,449,288-357) were delayed in comparison to the X-ray and optical observations. We obtained 13 spectra which were well distributed in phase. Exposure times were limited to 20 min to minimize phase smearing.

3. Results

To construct the light curves we used the ephemeris given by Patkós (1982):

$$\text{J.D.}_{\odot} = 2,433,777.42453 + 0.5930718E \tag{1}$$

In the optical light curve it was obvious that there was a significant deviation from a light curve without any spots. This deviation was more pronounced in the J.D. 2,449,254-57 light curve than the one obtained two month later at J.D. 2,449,310-11. We assumed photospheric spots only on the surface of the primary star, because the possible contribution of spots over the secondary star were to small to account significally to the light curve changes.

According to our analysis in the case of the first light curve there was a round dark spot with a radius of $27° \pm 12°$ at latitude $50° \pm 20°$ and longitude $78° \pm 2°$. In the light curve at 2,449,310-11 the maculation effect was much smaller. In that case we couldn't do detailed spot model analysis. We could only determine the latitude of this smaller spot to be at $37° \pm 7°$. The spot modelling procedure is described in detail in the papers by Hempelmann & Schöneich (1987) and Patkós & Hempelmann (1994).

As a first step to produce the X-ray light curve we binned photon counts into time-intervals of maximum 200 sec. Then to reduce scatter we binned the observational points in phase intervals of about 0.02. The resulting X-ray light curve shows the minimum bit later than photospheric mid-eclipse.

We modelled the X-ray light curve with two coronal emission regions over the primary star. (A detailed description of the model we used can be found at: Ottman, Schmitt and Kürster 1993). The X-ray spectrum of SV Cam can be explained by a two temperature plasma of $T_1 = 3 \times 10^6$ K and $T_2 = 1.5 \times 10^7$ K.

SV Cam is a single lined binary. The mutual blending of the absorption systems originating from the two components is therefore no problem, but because of the high rotational velocity neighbouring lines can blend each other significantly. This blending can affect the derived spot distribution by altering the shape of spectral lines. Therefore we had to use only lines which seemed to be blend-free. Our analysis was based on four absorption lines: CaI 6102.8 Å, CaI 6122.0 Å, Fe I 6400.0 Å and CaI 6439.1 Å.

First we determined $v \sin i = 117 \pm 3$ km s^{-1}. Together with i = 90° and $P_{rot} = 0.5934$ day this value yields a stellar radius of the primary of 1.3 $R_\odot$ and a radius of the secondary star 0.83 $R_\odot$ ($r_2/r_1 = 0.64$).

We obtained independent Doppler images of the four lines. A description of the technics we used can be found at; (Vogt, Penrod and Hatzes 1987). These maps we got are not identical, but are very alike, and first of all, they agree well with the map we obtained analysing the photometrical data.

According to the averaged picture, we got a spot distribution which is dominated by a strong circular spot around latitude 60° and longitude 75°. There seems to exist also an appendage to this spot with a longitude similar to the one we got from the J.D. 2,449,310-11 optical light curve. This also coincides with the position of one of the derived coronal X-ray emission regions. One possible explanation could be, that the at J.D. 2,449,254-57 observed spot might have vanished by J.D. 2,449,310 or drifted to a new position. As the spectroscopic observations were done later (between J.D. 2,449,288 and J.D. 2,449,357) - a new strong spot might have emerged at the original position.

This kind of rapid spot evolution seems to be the regular behaviour of SV Cam (Patkós 1982; Zeilik et al. 1988). Note, that because of the 90° unambiguouty we cannot distinguish between spots on the "northern" and "southern" hemispheres. The spots might be on one or on both hemispheres. May be the above mentioned spot and its appendage are not connected, they might be at different hemispheres, and therefore physically not related.

A third active region was also derived from the spectroscopic observations. It seemed to be near the equator at around latitude 270°. It had a lower contrast in our Doppler image map. Despite this, it had a position near the second coronal X-ray source which we derived from the ROSAT light curve. This indicates a complete magnetically active region at this position. The reality of this spot is further strengthened by the fact, that surface spots have been frequently observed at the same position (see e.g. Zeilik et al. 1988).

The large wavelength coverage of the Sandiford Echelle Spectrograph made it possible to acquire data simultaneously on Hα. These spectral profiles were examined to see if any rotational modulation which may be an indication of surface plage could be detected.

There is a strong distortion (pseudo-emission bump) in the red wing of phase 0.004 that might be due to the secondary. The secondary star with an estimated spectral type of K4 is considerably cooler than the primary and when it transits it appears as a dark spot against the primary's surface. It thus produces a pseudo-emission distortion in the spectral line profile in the same manner as does a cool surface spot.

4. Conclusions

The binary system SV Cam is one of the closest binaries among the RS CVn class and hence, if the binary nature of these stars is responsible for their apparently enhanced activity then SV Cam should exhibit a much higher coronal X-ray emission as expected from two normal active G2/K4 MS stars. However, the observed X-ray count-rate of this star corresponds to the expected value which has been derived from the Rossby number.

The X-ray light curve can be explained with a model of two localized coronal sources in the binary system. One source is located closer to the primary star (most probably 0.8 $R_\odot$ above its surface), the other source lies in the middle between the two stellar components. Therefore, it remains somewhat open whether this source has its origin in magnetism of the secondary star or the primary one or whether it results from an interaction of the two stellar magnetospheres.

We found two photospheric active regions on the primary star. The first active region has been exhibited by Doppler tomography to be of complex nature. Its main structure is a large spot of almost circular shape. This spot was also found from optical light curve analysis.

The optical light curve was completely explained with this spot alone. However, the Doppler image showed an additional feature in this active region: an appendage to the circular spot. The whole region looks similar to a spot group on the Sun although one has to keep in mind that there is latitude ambiguity with respect to the equator, so that the circular spot may be in the one hemisphere while the appendage might be in the other hemisphere.

The presence of this appendage (a second spot inside a common active region) produces a noticeable change in the light curve and this would have been detected by the photometric measurements. There are, two explanations to solve this contradiction. The first but less likely possibility is that it is an artifact in the Doppler image resulting from observational errors and noise. However, this feature is evident in all four spectral lines analyzed. Hence, we felt its existence was real. The other possibility was the assumption of a temporary development of an active region. The spectrograms were measured one month later than the light curve. Such rapid changes of spottedness might not be abnormal in case of SV Cam as some of the figures in the paper by Patkós (1982) demonstrate.

The finding of spots exclusively on the primary star does not imply inactivity or absence of spots on the secondary star. Normally they cannot be seen, neither in broad-band light curves nor in the absorption lines outside the primary eclipse because of a too little contribution of the secondary star to the total light output. However, this may not be the case during the primary eclipse. During this phase all the photospheric lines in the primary show absorption features that are believed to come from the secondary star. However, no such absorption feature is seen in the Hα profile, which should be present if the secondary were an inactive K4 star. The implication is that at primary eclipse the light from the secondary (at the wavelength of Hα) is predominantly continuum or possibly even in emission.

Further evidence of such activity is seen at secondary eclipse. The Hα line strength of the primary increases at this phase. This is expected because outside of eclipse light from the secondary fills in the absorption lines of the primary making them shallower. However, the increase in Hα line strength is a factor of 1.6 greater than that expected from the continuum (at 6563 Å) expected from the secondary for its spectral type. Again the conclusion is that the secondary is chromospherically active.

The Hα variations show rotational modulation with a maximum near phase 0.8 and minimum at near phase 0.3. It is not known whether the origin of this variation - if it is indeed real - originates with surface features on the primary or secondary stars. If the chromospheric plages which may be responsible for this variation are located on the primary, then they may be associated with the large photospheric spot found by the Doppler imaging and photometry. If the secondary star produces this variation then the stellar surface region below one X-ray source is the more active one. In each case, the conclusion is that the strong spot on the primary star, the enhanced chromospheric activity of the secondary star and an intermediate coronal X-ray source are correlated with each other in a physical sense.

It seems that the light from the secondary can have a strong influence on the Hα line strength and this will complicate interpretations of the Hα variations. Furthermore, there is some evidence for transient variations.

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Discussion

B. Schmieder: What is the difference of your two coronal sources? How they are related to the spots that you observed or you modeled from Ca I observations?

L. Patkós: The main difference between the two coronal sources is that one source seems to be connected with the magnetic field of both star components while the other one belongs only to the corona of the primary component. Both coronal sources are connected to spots in the photosphere of the primary component.

S. Antiochos: Is it possible to say anything about the magnitude of the magnetic field in the star spots?

L. Patkós: Unfortunately in the case of SV Cam we can only speak about the existence or non-existence of spots on the primary component. To discuss the magnitude of the magnetic field we would need much more detailed knowledge about these spots ...

Zs. Kővári: You were talking about a binary with a K and G component. Which one is supposed to be spotted and why? Can we exclude the possibility of spot activity on both components?

L. Patkós: Both components are supposed to be spotted, but because of the great brightness difference between the two stars photographically we can only measure the ones over the surface of the primary component. However Hα measurements give us strong evidences the secondary to be spotted too.