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Discovery of two short-period eclipsing binaries with active components*

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Abstract. We present high-precision UBV(RI)$_c$ photometry as well as soft X-ray light curves for the visual triple system HD 9770 and the visual binary HD 195434, obtained at the European Southern Observatory and extracted from the ROSAT all-sky survey, respectively. The optical photometry revealed that in both systems one component is a very short-period eclipsing binary showing also BY Dra-type variability. We have computed accurate orbital periods, deduced approximate physical parameters, spectral classifications, distances and X-ray luminosities and identified which component of each visual system is responsible for the optical variability. Futhermore, we find that both systems are variable in X-rays, but no correlation with the optical variability is seen.

Key words: stars: activity – stars: late-type – stars: variables – binaries: eclipsing – X-rays: stars – techniques: photometry

1. Introduction

Photometric and spectroscopic observations of known or suspected active stars have been carried out by the authors in recent years (see, among others, Cutispoto 1995; Cutispoto et al. 1990,1995,1996; Tagliaferri et al. 1994; Kürster et al. 1994) in order to provide crucial clues on properties such as the presence of optical variability, binarity, distribution and evolution of atmospheric inhomogeneities, rotation rate and Lithium abundance. We present here multicolor photometry of two visual multiple systems, i.e. HD 9770 and HD 195434, for both of which one component turned out to be an eclipsing binary of very short period. We derive accurate orbital periods, infer approximate physical parameters, spectral classifications and distances, and identify which component of the systems is responsible for the optical variability. As X-ray emission is an excellent tracer of coronal activity we complement the optical photometry with soft X-ray light curves of both objects, extracted from the ROSAT all-sky survey. We also derive X-ray luminosities for both objects.

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* based on data collected at the European Southern Observatory, La Silla, Chile

2. Observations

2.1. Multicolor photometry

Two of us (GC and SM) collected *UBV(RI)*$_c$ observations over the periods November 25 - December 5, 1994 (GC), August 19 - September 03, 1995 (SM), and October 1-12, 1995 (GC) at the European Southern Observatory (La Silla, Chile). They used the 50-cm ESO telescope equipped with a single-channel photon-counting photometer, a thermoelectrically cooled R943-02 Hamamatzu photomultiplier and standard ESO filters matching the $UBV(RI)_c$ system. In order to obtain accurate differential photometry for each presumably variable star, a comparison and a check star were also observed. Details on the observation and reduction procedures can be found in Cutispoto (1995). The observations were corrected for atmospheric extinction and transformed to the standard *UBV(RI)*$_c$ system. The typical error of our differential photometry is of the order of 0.005 magnitudes, with somewhat larger values (up to 0.01 magnitudes) in the *U*-band due to the lower photon counting statistics.

In Table 1 we give the brightest *V*-band magnitudes, the corresponding *U-B*, *B-V*, *V-R* and *V-I* colors and the most likely spectral types and distances we have inferred for the program stars. The typical accuracy of the absolute photometry in Table 1 is of the order of 0.01 magnitude, somewhat larger values are found for the *U-B* color. These errors were estimated from the accuracy of the *V* magnitude and colors of comparison and check stars we derived via standard stars (cf. Table 2).

Table 1. Minimum *V*-band magnitudes (V_{min}) and corresponding colors, most likely inferred spectral type (SpT), distance (D) and X-ray luminosity (log L_x) for the program stars

Program star	V_{min}	U-B	B-V	V-R_c	V-I_c	SpT	D(pc)	log L_x
HD 9770	7.11	0.58:	0.92	0.54	1.07	A = K1/2 V	20	30.2
						B = K4 V + K4/5 V		
						C = M2 V		
HD 195434	8.71	0.47:	0.87	0.53	1.01	A = K3 V + K6 V	42	30.3
						B = K2 V		

Table 2. *V* magnitudes and colors for the comparison and check stars. The estimated errors for these values are of the order of 0.01 magnitudes. The symbol ":" denotes errors of the order of 0.02 magnitudes

Star	V	U-B	B-V	V-R_c	V-I_c
HD 10002	8.13	0.59:	0.85	0.45	0.85
HD 10216	6.56	1.10:	1.15	0.59	1.13
HD 196124	8.92	0.81:	0.96	0.57	1.04
HD 196573	7.89	2.01:	1.64	0.91	1.89

2.2. Period determination, inferred spectral classification and physical parameters

We determined the orbital periods and errors by matching the eclipsed part of the light curves obtained in different seasons, taking into account the photometric precision.

Our multicolor photometry was used to infer, at least approximatively, the spectral type, luminosity class and distance of the program stars, following the approach described in Cutispoto et al. (1995). Moreover, to improve the reliability of our results, we used the program *"Binary Maker 2.0"* (BM2.0; Bradstreet 1993) in order to fit the observed light curves and derive important physical parameters, such as masses and radii of the eclipsing stars. Although both the procedure developed by Cutispoto et al. (1995) and the program BM2.0 can produce non-unique solutions, the combination of the two methods allowed us to identify a common set of consistent results for each star. The computed physical parameters, given in Table 3, are consistent with the physical parameters of stars as listed in Schmidt-Kaler (1982).

In order to fit the curved out-of-eclipse light curves we had to assume the presence of photospheric spots. Based on our data alone we cannot ascertain on which component of the eclipsing binaries spots are located. However, for simplicity, we report only the case in which spots are placed on the brighter of the two components.

2.3. Soft X-ray data from the ROSAT all-sky survey

Data from the ROSAT all-sky X-ray survey were used to obtain soft X-ray light curves of HD 9770 and HD 195434. The PSPC detector with an energy bandpass of $0.1 - 2.4$ keV was at the focus of the X-ray telescope (see Trümper 1983 and Pfeffermann et al. 1987 for a description of the satellite and instrument). During the ROSAT all-sky survey the sky was scanned in great circles (see Voges 1992;1993 for details). A specific celestial object was typically covered for up to 30 sec in several of these scans that were spaced by 96 min, therefore, time variability studies became possible (e.g. Kürster 1995). To be more precise the number of scans in which a specific source is seen depends on its ecliptic latitude. If a sources is located within one field-of-view radius from the ecliptic poles then it is seen in every scan, if it is located at the ecliptic itself then it is visible only in 30 scans distributed over 2 days.

3. Results and discussion

3.1. HD 9770 = GL 60

HD 9770 = GL 60 is a visual triple system whose components AB and C were classified as K3V and M2V, respectively (Edwards 1976; Woolley et al. 1970, Gliese 1969). Houk (1982) lists the spectral classification K1 V for the whole system. HD 9770 was identified as an IRAS point source by Wolstencroft et al. (1986) and as a suspected variable in the optical by Petit (1990) and Baize & Petit (1989). The source was clearly detected during both the all-sky EUV surveys obtained with the WFC on board the ROSAT satellite (Pounds et al. 1993, Pye et al. 1995) and with the EUVE satellite (Malina et al. 1994).

At the 50-cm ESO telescope, due to the small angular separation ($\simeq$ 0.2 arcsec), the three components of HD 9770 were always included into the diaphram of the photometer we used. Photometric observations obtained by us in late 1993 (Cutispoto et al. 1995) indicated the presence of optical variability with a period of 6.29 $\pm$ 0.24 days and an amplitude of about 0.07 magnitudes in the *V* band. In the same paper, however, from few further observations obtained in January 1995, we had already reported (in a note added in proof) that HD 9770 was an eclipsing binary, although an accurate value of the variability period could not be derived at the time the above-mentioned paper was in press. From the observations presented in this paper, obtained over an interval of almost one year, we are now able to confirm the presence of two almost identical primary and secondary eclipses and to derive an orbital period of 0.476533 $\pm$ 0.000033 days, that is shorter than any photometric or orbital period known to date for active stars (Strassmeier et al. 1993). The resulting *V*-band light curves and colors, where phases are reckoned from the ephemeris HJD = 2449311.3731 + 0.476533 $\cdot$ E, are shown in Fig. 1 and 2 for the 1994 and 1995 data, respectively. The 6.29-day period reported in Cutispoto et al. (1995) turned out to be an alias value of half of the real period. This is due to the circumstance that in late 1993 the star was observed

Table 3. Physical and spots parameters of the eclipsing binaries in the visual system HD 9770 and HD 195434, obtained from the October 1995 light curves by using the BM2.0 program

	HD 9770		HD 195434		
	physical parameters		physical parameters		
Component	B_1	B_2	A_1	A_2	
$M/M_{\odot}$	0.73±.02	0.67±.02	0.72±.02	0.64±.02	
$R/R_{\odot}$	0.73±.004	0.72±.004	0.77±.003	0.70±.003	
$T_{star}(K)$	4450±50	4350±50	4730±50	4200±50	
i (deg)	76.7±0.5		80.2±1.5		
a ($R_{\odot}$)	2.87±.004		3.02±.003		
	spot parameters[1]		spot parameters[2]		
Latitude	30±5		-19±3	45±5	35±5
Longitude	205±10		60±5	200±5	110±5
Radius (deg)	15.5±1.0		13.4±0.7	16.0±0.5	12.0±1.0
T_{spot}	3780±200		4020±200	4020±200	4020±200

(1): spot on component B_1
(2): spot on component A_1

just once every night so that the real periodicity was not sufficiently sampled. Moreover, HD 9770 is an eclipsing binary whose light curve has two maxima and two minima per cycle, while our earlier period of 6.29 days was calculated assuming a simple sinusoidal modulation because no eclipses were covered in 1993. The new *V*-band light curve based on the data obtained in 1993, but with phases computed with the new period of 0.476533 days, is shown in Fig. 3.

In Fig. 1 and 2, besides the presence of a curved and variable out-of-eclipse light curve, it is very interesting to note the peculiar behavior of the color indices. They become bluer in coincidence with both light minima, while for a *"normal"* eclipsing binary (see for instance Fig. 2 in Cutispoto 1995 and Fig. 7 of this paper) the colors become redder when the hotter star is eclipsed (i.e. at primary mimimum) and bluer when the cooler star is eclipsed (i.e. at secondary mimimum). We can quantitatively explain this peculiar behavior by assuming that the component B of the system is an eclipsing binary, consisting of a K4/5 V (B_1) and a K5 V (B_2) star, while the component A is a K1/2 V star. The *V* magnitudes of these components A and $B_1 + B_2$ are comparable (e.g. Holden 1978), but the colors of the former are bluer. Hence, during both eclipses the relative contribution of the cooler B system to the total light decreases, so that the system A + B appears bluer at both minima. The computed colors of such a multiple system, including the much fainter component C, are consistent with the observations. The component C is too faint to generate the observed light variations.

The physical parameters obtained, with the program BM2.0, for the components B_1 and B_2 are given in Table 3.; the fit of the October 1995 *V*-band light curve is shown in Fig. 4. In order to reproduce the out-of-eclipse light curve we assume that a spotted region, covering about 8% of the photosphere, is present on the component B_1 (Table 3). Finally, from the spectral classification inferred above, and the spectral-type vs. absolute magnitude relation computed by Cutispoto et al. (1995), we estimate for HD 9770 a distance of about 20 pc, that is in good agreement with the trigonometric value of 18 ± 4 pc reported by Woolley et al. (1970) and by Gliese (1969).

The ROSAT all-sky survey X-ray light curve of HD 9770 is shown in Fig. 5 where the PSPC count rate is plotted vs. Julian day and vs. the orbital cycle according to the ephemeris we determined from the optical photometry. The light curve represents the combined flux from all components of the HD 9770 multiple system, which is totally unresolved due to the fact that the typical spatial resolution in the X-ray all-sky survey is of the order of 1 arcmin. Each data point corresponds to photons collected during an individual scan. As it can be seen from Fig. 5, the object was observed over more than 2 days with an additional single scan obtained after a gap of about 160 days. HD 9770 turns out to be a strong and clearly variable X-ray source. Using the count rate-to-flux conversion (dependent on the hardness ratio) given by Schmitt et al. (1996) and the 20 pc value for the distance, we determine a mean X-ray luminosity of $\log L_{\rm x} = 30.2$ (where $L_{\rm x}$ is in erg $\sec^{-1}$). This value is at the high end of the distribution of X-ray luminosities for BY Dra-type binaries, as can be inferred from the catalogue of chromospherically active binary stars (Strassmeier et al. 1993). Moreover, it results in good agreement with the correlation between $L_{\rm bol}$ and $L_{\rm X}$ found by Pallavicini et al. (1990) for the full sample of UV Ceti and BY Dra-type stars observed with EXOSAT. This correlation is probably due to the presence of a "saturation" level, with the brightness per unit area being approximately constant and the total X-ray luminosities increasing with the bolometric luminosity (e.g. Fleming et al. 1989;1995, Stauffer et al. 1994, Randich et al. 1995;1996). Both $L_{\rm bol}$ and $L_{\rm X}$ of HD 9770 are larger than those of the objects in the Pallavicini et al. (1990) sample of BY Dra-type binaries, thus extending that correlation to the highest luminosity values. Here we have assumed that all the X-ray flux of HD 9770 is due to the active component B of the system. In fact, although both the M and K stars can be X-ray emitters, as normal field stars their X-ray luminosities should be orders of magnitude below the $\log L_{\rm x} = 30.2$ value (Fleming et al. 1995).

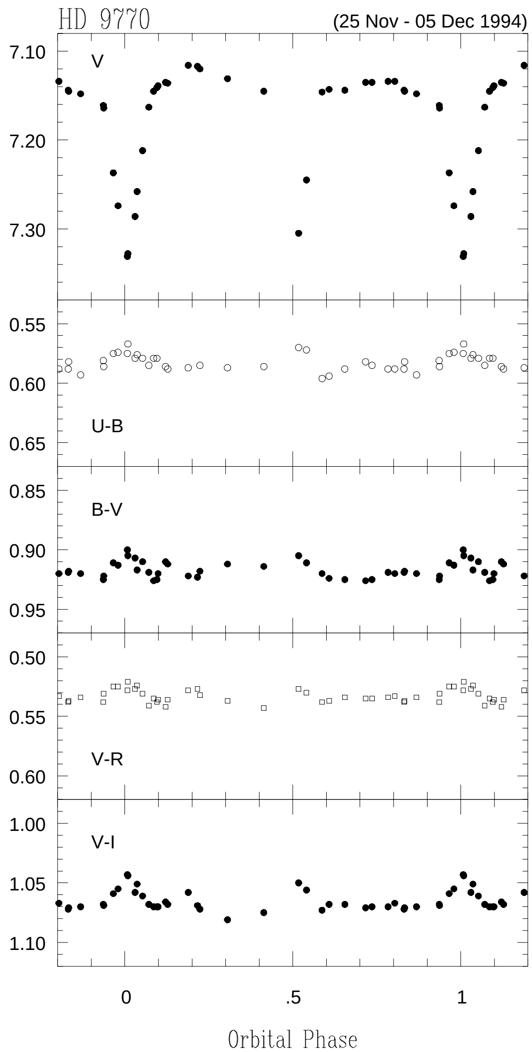

Fig. 1. V light curve and colors of HD 9770 obtained over the time interval 1994, November 25 - December 5. Phases are reckoned from the ephemeris HJD = 2449311.3731 + 0.476533 x E. Note that HD 9770 appears bluer at both eclipses because the colors of the triple visual system, to which it belongs, are dominates by the bluer nearby visual component. See also the discussion in Sect. 3 and the well covered light curve in Fig. 2

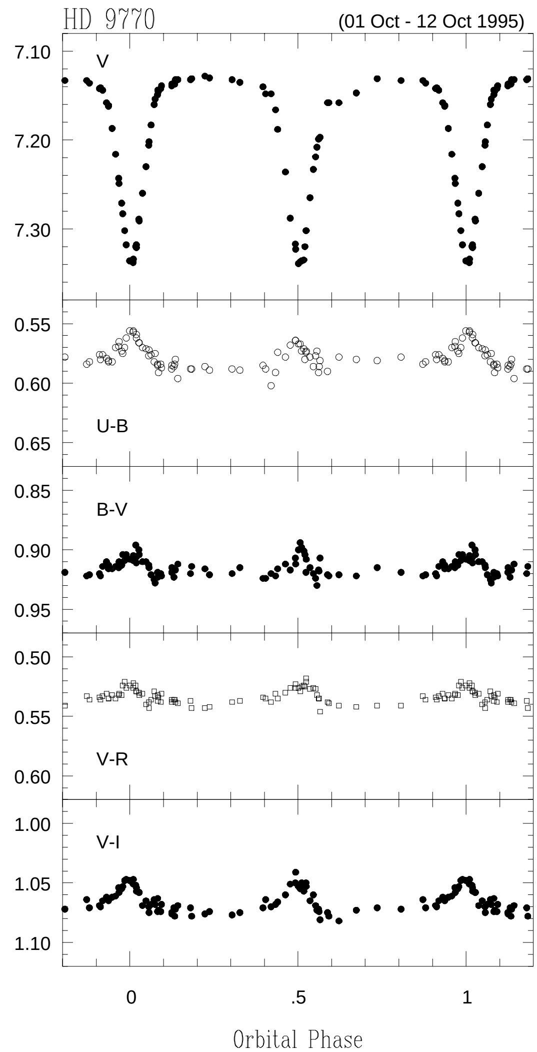

Fig. 2. As Fig. 1 for the time interval 1995, October 1-12

One pronounced short-duration flare is seen near JD 2,448,086.4. Contrary to the optical light curve which shows both eclipses and phase correlated rotational modulation typical for spotted late-type stars, no systematic dependence of the X-ray flux variations on orbital phase is observed.

3.2. HD 195434

HD 195434 is a high proper-motion star included both in the *Lowell Proper Motion Catalog* (Giglas et al. 1971) and in the *New Luyten Two-Tenth Catalog* (Luyten 1979). It was clearly detected at EUV wavelenghts with the ROSAT WFC (Pye et al. 1995). It is a visual binary (ADS 13940) and, due to the angular separation of only 1.66 arcsec (Holden 1978), both components were always included into the diaphram of the photometer we used. From the observations obtained in August - September and October 1995 we discovered that one of the two stars of ADS 13940 is an eclipsing binary and computed an orbital period of 0.52175 $\pm$ 0.00022 days. Note that the errors on the periods of HD 195434 and HD 9770 are different due to the different time intevals covered by our observations. The resulting *V*-band light curves and colors, where phases are reckoned from the ephemeris HJD = 2449950.279 + 0.52175 $\cdot$ E, are shown in Fig. 6 and 7. The curved and rather stable out-of-eclipse light curve has a peak-to-peak amplitude of about 0.04 magnitudes in the *V*-band, indicating the presence of photospheric spots. The out-of-eclipse *V* magnitudes and colors obtained from our observations appear to be in good agreement with those (*V*=8.74, *B*-*V*=0.87, *U*-*B*=0.44) reported by Carney et al. (1994), while it is likely that the *V* magnitude and colors (*V*=8.83, *B*-*V*=0.89, *U*-*B*=0.44) reported by Sandage & Kowal (1986) were obtained while one of the eclipses was underway.

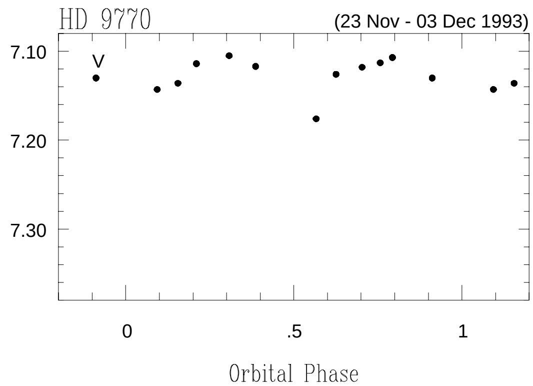

Fig. 3. V light curve of HD 9770 obtainded over the period 1993, November 23 - December 3. This is the same data set plotted in Fig. 1 by Cutispoto et al. (1995), but now plotted with phases reckoned from the new ephemeris HJD = 2449311.3731 + 0.476533×E

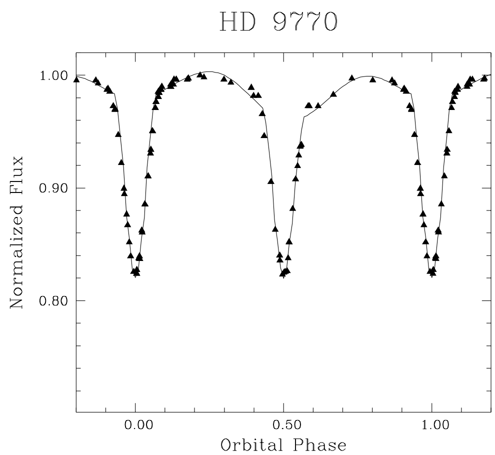

Fig. 4. Fit of the October 1995 V light curve of HD 9770 obtained by using the program BM2.0; the physical and spot parameters are listed in Table 3

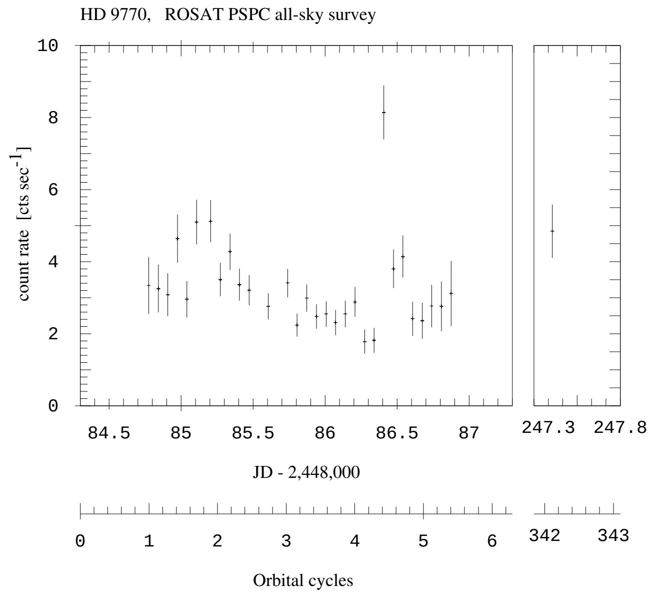

Fig. 5. ROSAT all-sky survey X-ray light curve of HD 9770. The measured PSPC count rate is plotted vs. Julian day as well as vs. the orbital cycle of the short-period eclisping binary in the system. Each data point corresponds to an individual survey scan. Due to the error of the orbital period the phase uncertainty of the X-ray data with respect to the photometric data is of the order of ± 0.2 phase units; note the data gap of approximately half a year after which the object reappeared in a single scan

The SIMBAD database reports for HD 195434 the values *V*=11.01, *B-V*=0.70 and *U-B*=0.26 after Muzzio (1973). These values are very different from those obtained by us, by Carney et al. (1994) and by Sandage & Kowal (1986). Moreover, from data in Fig. 7 and the fit in Fig. 8 it is also evident that, although the primary minimum was not fully covered, the minimum luminosity of HD 195434 cannot be much fainter than $V \simeq 9.06$. The reason for the discrepancy between the data by Muzzio (1973) and the more recent photometric observations is not clear, unless the former refer to a different star.

Due to its proper motion and metallicity ([m/H] = -0.99; Carney et al. 1994, Sandage & Kowal 1986), HD 195434 can be classified as a halo population or an old disk star, so that its very short rotation period and the presence of photospheric spot activity and eclipses make it a rather interesting object. In order to infer the spectral classification of both components A and B, we started from the K2 + K2 classification reported by Bidelman (1985) and assumed that the difference in brightness between the two components ($\Delta V_{A-B} \simeq 0.2$) given by Bidelman (1985) and Holden (1978) was not obtained during one of the eclipses (the two eclipses embrace only about 35% of the light curve), but is due to the presence of a component A_2. Hence, we inferred that the brighter component of the visual double ADS 13940 is the eclipsing binary and the best fit of the *V* light curve and colors, that satisfies the condition ($\Delta V_{A-B} \simeq 0.2$), was obtained by assuming K2 and K6 dwarf components. For such a system we estimate a distance of 42 pc. If we attributed the light variation to the fainter component B, then, in order to obtain a 0.2 magnitudes difference at maximum brightness between the A and B_1 +B_2 stars, the system would have to be formed by K2 (A) and K4 + K7 (B_1 +B_2) dwarf components and its distance would turn out to be about 39 pc. However, we rule out this alternative classification because, assuming the eclipsing component to be fainter than the visual companion, it would imply that during both eclipses the color indices should turn bluer, similar to what is observed for HD 9770, which is not the case (see Fig. 7).

The physical parameters obtained for the components A_1 and A_2 are given in Table 3; the fit of the October 1995 *V*-band light curve is shown in Fig. 8. In order to reproduce the out-of-eclipse light curve we assume that three spotted regions, covering about 23% of the photosphere, are present on the component A_1 (Table 3).

Fig. 9 shows the ROSAT all-sky survey X-ray light curve of HD 195434 where we have plotted the PSPC count rate

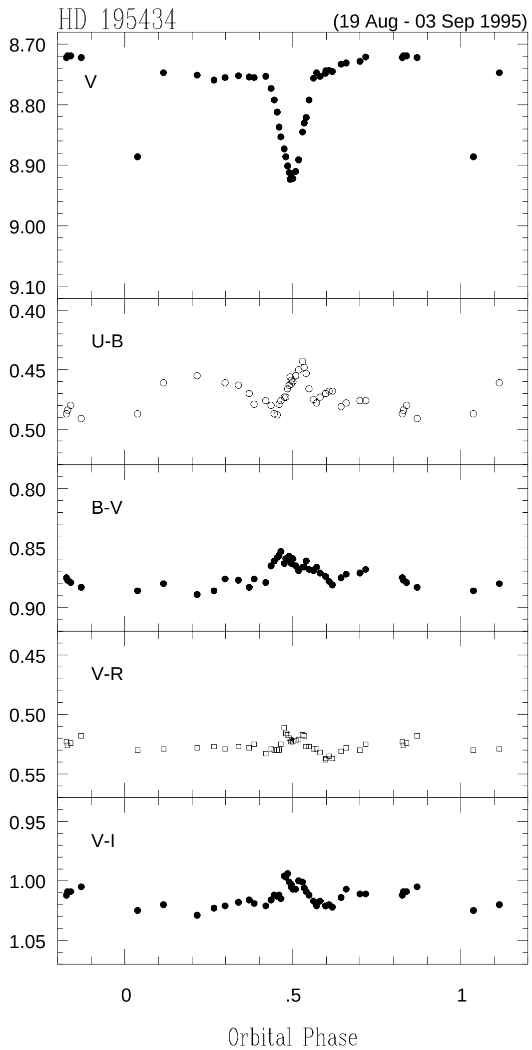

Fig. 6. V light curve and colors of HD 195434 obtained over the period 1995, August 19 - September 3. Phases are reckoned from the ephemeris HJD = 2449950.279 + 0.52175×E

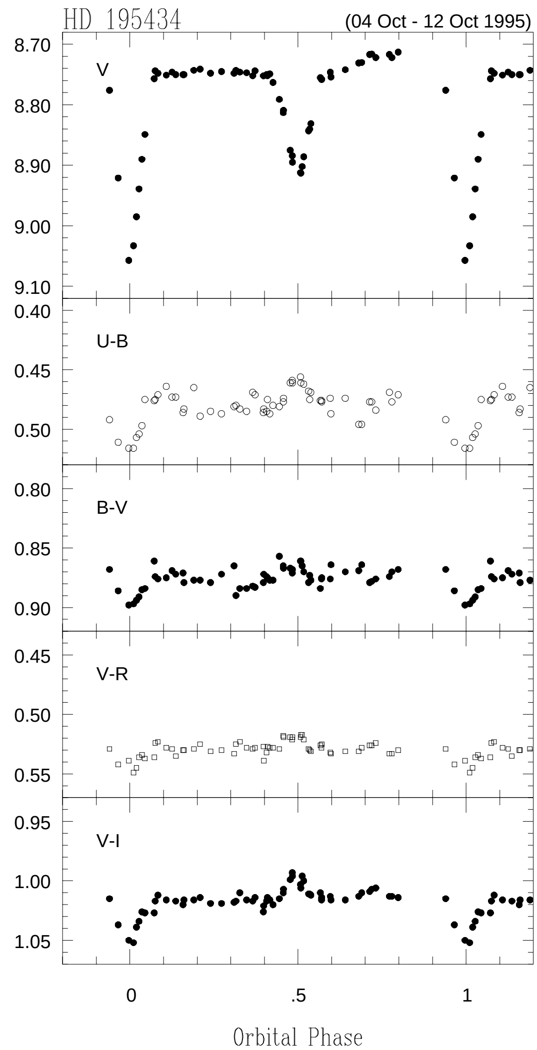

Fig. 7. As Fig. 4 for the time interval 1995, October 4 - 12

vs. Julian day and vs. the orbital cycle according to the ephemeris determined from the optical photometry. As for HD 9770 the light curve represents the combined flux from all components of HD 195434, and each data point corresponds to an individual survey scan. HD 195434 was observed over almost 2 days revealing variability of the X-ray flux by a factor of ≈ 2, but no indication that this variability is related to the optical light curve. In the same way as for HD 9770 we determine the mean X-ray luminosity of HD 195454 to be $\log L_{\rm x} = 30.3$. Thus we infer almost identical X-ray luminosities for the two objects discussed in this paper. As for HD 9770, the $L_{\rm bol}$ and $L_{\rm X}$ values of HD 195434 fit the correlation between those two parameters by Pallavicini et al. (1990), with HD 195434 being placed towards the higher end portion of this correlation. For the same reasons as for HD 9770, we assumed that all the X-ray flux is due to the active component A of HD 195434. We note that the observed high X-ray luminosity of HD 195434 is in line with the findings that short period binaries in the galactic halo population or in old open cluster can still have strong chromospheric and coronal activity (Pasquini et al. 1991; Belloni et al. 1993; Belloni & Verbunt 1995; Fleming & Tagliaferri 1996).

4. Conclusions

We have presented multicolor photometry and ROSAT X-ray light curves of two late-type visual multiple systems (HD 9770 and HD 195434) and have shown that each system contains a very short period eclipsing binary component. In particular, HD 9770 contains the chromospherically active star with the shortest period known to date, while HD 195434 can be classified as a halo population or an old disk star, so that its very fast rotation and the presence of strong activity and eclipses make this star a very interesting object. We have identified which component of each visual system is the eclipsing binary and have derived accurate orbital periods, approximate spectral classifications, major physical parameters, distances, and X-ray luminosities.

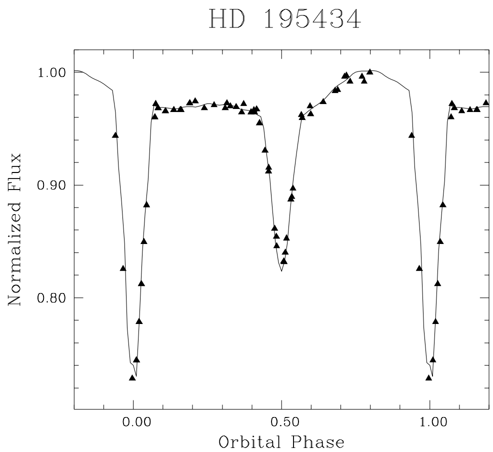

Fig. 8. Fit of the October 1995 V light curve of HD 195434 obtained by using the program BM2.0; the physical and spot parameters are listed in Table 3

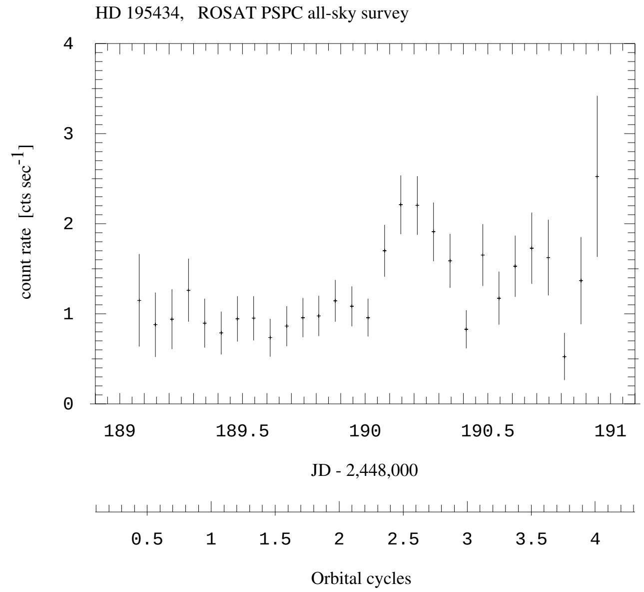

Fig. 9. ROSAT all-sky survey X-ray light curve of HD 195434. The measured PSPC count rate is plotted vs. Julian day as well as vs. the orbital cycle of the short-period eclipsing binary in the system. Each data point corresponds to an individual survey scan. The phase uncertainty of the X-ray data with respect to the photometric data is of the order of ±1.0 phase units

On account of the inferred characteristics we conclude that both stars belong to the BY Dra-type class of intrinsically variable spotted stars.

We confirm the existence of a good correlation between L_{bol} and L_X for this type of stars, extending this correlation toward the higher end of the X-ray luminosities. We also confirm that stellar activity enforced by synchronous orbital rotation in short period binaries is still present in stars as old as HD 195434.

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