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ASTRONOMY AND ASTROPHYSICS

The variation of photospheric active regions in HD 127535 *, **

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Summary. *UBVRI* photometry of the chromospherically active star HD 127535 obtained during April 1987 is presented. The analysis shows that the light variation is quasi-sinusoidal and the amplitude and the phase of the light minimum have changed drastically compared to the previous observations. These changes are attributed to the formation and evolution of magnetically active regions on the stellar surface. Furthermore, a quantitative analysis of the observations available in the literature since 1981 indicates that the sudden changes in activity on HD 127535 may be caused by short-lived spot groups rather than a single spot of longer life time. The maximum activity on HD 127 535 occured during 1985.

Key words: RS CVn systems – photometry-spot – areas – stellar atmospheres

1. Introduction

The activity in RS CVn systems and related stars has been a subject of detailed investigation during the past decade. These systems exhibit strong chromospheric, transition region and coronal emissions and periodic variations in optical light. The phenomenology of RS CVn systems is attributed to the presence of photospheric spots which are areas of lower temperature than the surrounding photosphere, covering a significant fraction of the stellar disc and are accompanied by hotter chromospheric active regions like plages.

HD 127 535 is one of the most active RS CVn stars showing strong and variable chromospheric and coronal emissions. Weiler and Stencel (1979) classified HD 127 535 as an RS CVn star due to the presence of strong Ca II H and K emissions. The observations of Collier (1982a) revealed that the star is a single-lined spectroscopic binary with an orbital period of six days. The spectral type of the visible component is K 2 IV/Ve (Houk and Cowley, 1975). It is one of the few RS CVn systems which exhibit Hα in emission. The optical light variability was discovered by Collier (1982b). Photometry by Udalsky and Geyer (1984) showed that the light variation has also a periodicity of about 5.97 days. The amplitude and the shape of the light curve change with in a few photometric cycles. Such variations are typical of RS CVn systems and are caused by the rotational modulation of spots or spot groups that are cooler than the photosphere. Due to the magnetically very active nature of this system, spots and/or spot groups form and disintegrate fairly rapidly on the stellar photosphere causing prominent changes in the chape of the light variation and the maximum light level. Innis et al. (1985) discovered strong emissions in 8.4 GHz and 22 GHz and their observations indicate a possible correlation between the radio emission and the spot visibility. In this paper we present the recent photometry of HD 127 535 and an analysis of the evolution of active regions since 1981.

2. Observations

UBVRI photometric observations of HD 127 535 were carried out during 12 consecutive nights in April 1987 using the 50 cm telescope of the European Southern Observatory (ESO), La Silla. A cooled RCA 31034 photomultiplier tube and a photon counting system were used. About 30 Cousins photometric standards in the E-regions (Vogt et al., 1981) were measured for the conversion of the instrumental magnitudes to the standard photometric system. The measurements were made differentially with respect to the comparison star HD 128 227. HD 128 618 was also observed to check the constancy of the comparison star. The photometric observations of HD 127 535 are listed in Table 1. The mean magnitudes and colors of the comparison and check stars are given in Table 2.

3. Photometric results

The phases of the light curve were calculated by means of the light elements given by Udalsky and Geyer (1984).

$$\mathrm{J.D.}_{\mathrm{hel}} = 2445804.10 + 5^{\mathrm{d}}.97 . E$$

Figure 1 shows V, $U-B$, $B-V$, $V-R$, and $V-I$ light and color curves of HD 127 535. The V light curve is quasi-sinusoidal with an amplitude of $0^{\mathrm{m}}.11$ and a phase position of minimum light at 0.67 P. The brightness at maximum and minimum are $8^{\mathrm{m}}.663$ and

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* Based on observations collected at the European Southern Observatory La Silla, Chile
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Table 1. Magnitudes and colors of HD 127535

JD (hel.) 2446000+	V	$U-B$	$B-V$	$V-R$	$V-I$
896.661	8.703	0.789	1.079	0.618	1.211
896.813	8.695		1.073	0.620	1.212
897.602	8.674	0.790	1.077	0.622	1.209
897.679	8.663	0.795	1.083	0.607	1.204
897.800	8.684	0.799	1.085	0.626	1.208
898.599	8.699	0.804	1.087	0.623	1.217
898.747	8.701	0.786	1.093	0.613	1.208
898.864	8.714		1.087	0.621	1.210
899.589	8.742	0.794	1.076		1.211
899.726	8.744	0.811	1.074	0.611	1.212
899.844	8.756		1.074	0.622	1.209
900.601	8.774		1.096	0.622	1.218
901.601	8.760				
902.589	8.700	0.811	1.086	0.611	1.213
902.735	8.704	0.795	1.077	0.618	1.213
903.586	8.692	0.796	1.064	0.637	
903.738	8.684	0.799	1.066	0.637	1.223
903.854	8.673	0.770	1.073	0.632	1.214
904.586	8.708	0.815	1.068	0.622	1.225
904.731	8.720	0.812	1.069	0.633	1.223
905.588	8.744	0.811	1.069	0.613	1.208
906.771	8.766	0.818	1.099	0.634	1.233
906.810	8.769	0.821	1.091	0.620	1.233
907.821	8.751	0.811	1.087	0.632	1.219

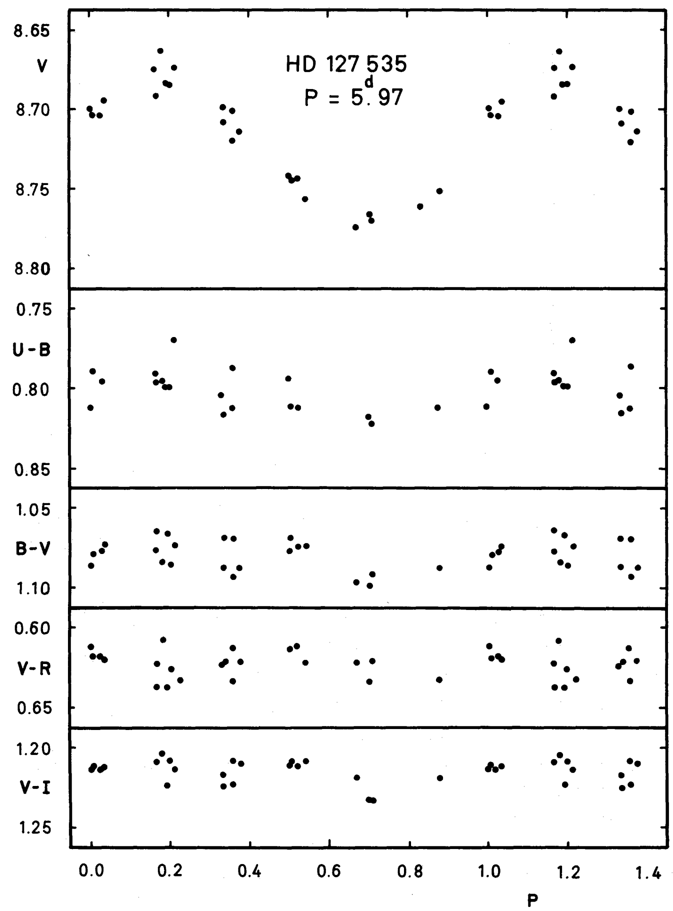

Fig. 1. V band light and color curves of HD 127535 plotted as a function of phase for a period 5.97 days

Table 2. Magnitudes and colors of comparison stars

Star	V	$U-B$	$B-V$	$V-R$	$V-I$
HD 128227	8.326 ±0.005	0.805 ±0.009	1.069 ±0.005	0.567 ±0.005	1.099 ±0.004
HD 128618	8.028 ±0.007	1.618 ±0.020	1.465 ±0.006	0.774 ±0.005	1.474 ±0.006

8^{m}774 respectively. Though the color curves do not show well-defined variations, the star tends to become redder at light minimum. Figure 2 shows the average V light levels and light curve amplitudes at different instants since 1981. The previous photometric observations of HD 127 535 are from the published data of Collier (1982b), Udalsky and Geyer (1984), and Bopp et al. (1986). The length of the bar corresponds to the amplitude of light variation of that epoch. The observations of Collier (1982b) showed that the light curve had the smallest observed amplitude of 0^{m}07 in 1981. In 1984 the amplitude increased to 0^{m}25 and the colour curve showed a well-defined $B-V$ variation. The amplitude decreased to 0^{m}204 in 1985 and to 0^{m}11 in 1987. The phase of the light minimum, corresponding to the location of the main spot group that is responsible for the observed light and color variations, also changed considerably between 1984 and 1987. A more close inspection of the light curves of 1984, 1985, and 1987 indicates that there is a correlation between the light curve and the color curve amplitudes in the sense that as the amplitude of light variation decreases the shape of the color curve changes from a well-defined one to a "Scatter diagram". Also the maximum brightness dropped from $V=8^m505$ in 1984 to $V=8^m663$ in 1987.

4. Interpretation

It is now an established fact that magnetically active regions with lower temperature than the surrounding photosphere are the main cause of the light variations observed in RS CVn systems and BY Dra stars. Observations of RS CVn systems covering several periods (e.g. Mekkaden et al., 1982; Bartolini et al., 1983) showed

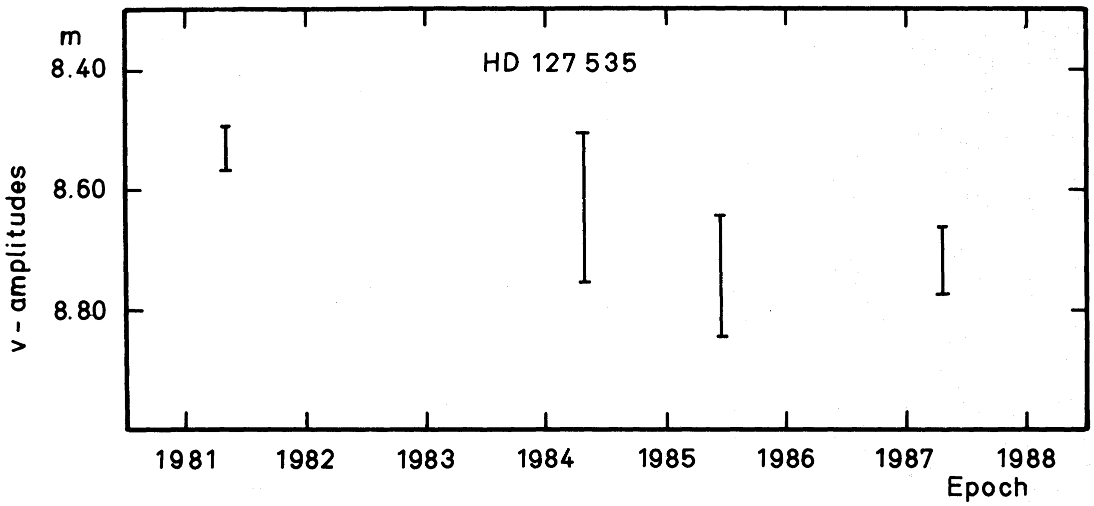

Fig. 2. Variation of mean light with time. The length of the bars corresponds to the amplitude of the V light curve at that particular epoch

that the areas covered by spots change within a few cycles causing drastic changes in amplitudes and shapes of light curves. Due to the very high magnetic activity in spots, bright chromospheric areas overlap the spots due to the magnetic heating of the chromosphere (Gondoin, 1986). The different spot groups may merge to form a single spot group as time proceeds and such a phenomenon has been observed in the RS CVn star II Peg (Mekkaden, 1987).

Several methods exist in the literature to model spots to reproduce the light variations of RS CVn and BY Dra stars. (e.g. Torres and Ferraz-Mello, 1973; Bopp and Noah, 1980; Dorren and Guinan, 1982). Vogt and Penrod (1983) developed the Doppler Imaging Technique using spectra of high resolution to map the photospheric spots. Though the two-spot models can reproduce the light variations of RS CVn systems, their interpretation may not be representative to the real picture of spot groups. Also the structure of spots may not be the same in RS CVn systems of different levels of activity and rotational periods.

HD 127 535 being one of the most active stars, the two-spot model is not an ideal assumption to explain the light variations. Several spots or spot groups may be responsible for the large amplitudes observed in 1984 and 1985. In order to get an idea of the spot coverage on HD 127 535 at different epochs, we have used the expression of Bopp and Noah (1980).

$$m_\lambda = -2.5 \log \{1 - f[1 - B_\lambda(T_{spot})/B_\lambda(T_*)]\},$$

where m_λ is the amplitude of light variation at wavelength λ T_{spot} and T_* are the spot and photospheric temperatures, f is the maximum fraction of the stellar disc covered by spots and $B_\lambda(T)$ is the Planck function. In this simple relationship the inclination of the rotational axis, the limb darkening and the differential line blanketing between the spot and the normal stellar photosphere are not taken into account. T_{spot} and f can be estimated by a non-linear least square fitting to the above expression. As only V values of HD 127 535 are available for 1981 and UBV values for 1985, comparative study of the spot activity at different epochs is possible only for V amplitudes.

Spectroscopic observations of another RS CVn system V 711 Tau by Ramsey and Nations (1980) showed that the spot temperature is normally cooler by 1000 K than the surrounding photosphere. The light maxima at different epochs of HD 127 535 show that both hemispheres of the star are spotted most of the time with one hemisphere more heavily than the other. The difference in the extent of areas of coverage of spots on both hemispheres causes the light variation at any epoch. So observed amplitudes need not correspond to the magnitude difference between the spotted and the "immaculate" surfaces. The available data show that the maximum observed brightness is $8^m.5$ in V. We have therefore assumed that this value is the nearest approximation for the magnitude of the "immaculate" surface. The estimated amplitudes correspond to the magnitude differences between this maximum brightness ($8^m.5$ in V) and the brightnesses at minima of each epoch. Assuming a photospheric temperature of $T_* = 4300$ K for HD 127 535 we have calculated values of f for spot temperatures 3100 K, 3300 K, 3500 K and 3700 K for each epoch. These correspond to the fractional coverage f of spot areas on the heavily spotted surface. Table 3 gives the spot areas calculated for different spot temperatures for each epoch and they

Table 3. Fractional coverage of spot areas

Epoch	Observed amplitude V	Estimated amplitude V	f(%) for T_{spot}			
			3100 K	3300 K	3500 K	3700 K
1981.33	0.070	0.070	7	8	9	11
1984.31	0.250	0.255	29	31	35	42
1985.44	0.204	0.340	41	45	50	60
1987.29	0.111	0.274	32	34	38	46

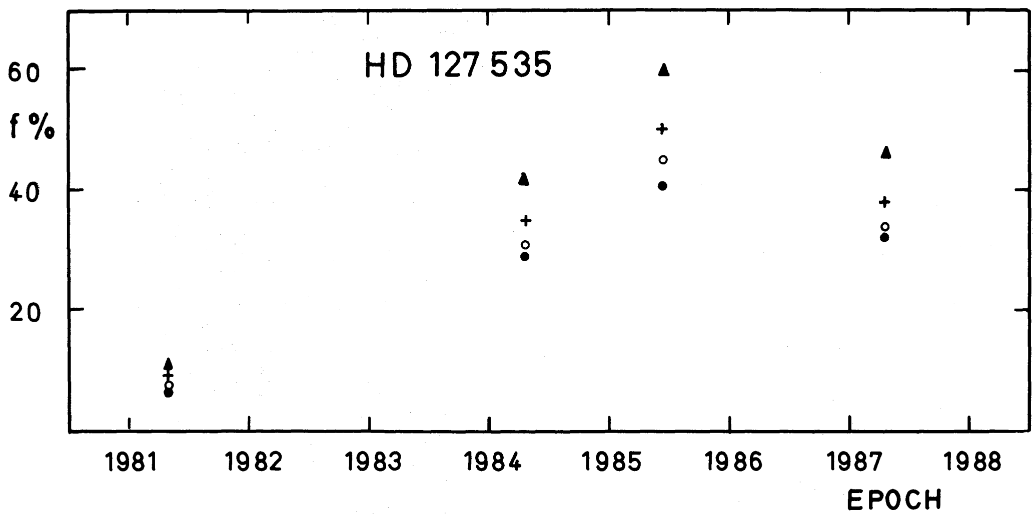

Fig. 3. Estimated spot areas for spot temperatures 3100 K (filled circles), 3300 K (open circles), 3500 K (pluses), and 3700 K (filled triangles)

are plotted in Fig. 3. It is clearly seen from Fig. 3 that the area occupied by spots decreases as the spot temperature decreases. The light curves of HD 127 535 since 1981 had always shown quasi-sinusoidal form. The presence of very large spots can be excluded as these would cause flat minima. However, if the spot group is located near the polar region, large areas of coverage cannot be ruled out. This case can be verified by spectroscopic and photometric observations. Spots cooler than 1200 K compared to the surrounding photosphere are preferred to explain the activity on HD 127 535. Figure 3 shows also that the maximum activity occurred during 1985 and the star seems to have an activity cycle of about seven years. Further photometry is necessary to determine the activity cycle more precisely.

Any change in shape or amplitude of light variation in RS CVn systems and related stars can be due to the cumulative effect of many small spots as suggested by Eaton and Hall (1979). Due to the high activity levels of these systems spots appear or disintegrate within a short time scale and hence the phase of the light minimum changes accordingly. So the picture of a long lived large spot or two spots is very crude and may not be correct. Uchida and Sakurai (1983) suggested that an "Active Longitude Belt" on the stellar photosphere as seen on the sun (Bumba and Howard, 1969) is preferable to the giant spot picture to explain the peculiarities of RS CVn systems. Spot groups appear, drift across and disappear in this zone causing changes in the light curve.

Spectroscopic observations of chromospheric lines are necessary to locate the chromospheric plage areas that overlap the photospheric spots. Observations of TiO bands, that are temperature indicators, will give an idea of the spot temperature of HD 127 535.

5. Conclusions

Analysis of the photometry of HD 127 535 since 1981 shows that the star is one of the most active RS CVn systems with large scale spot activity. Active regions covering up to 40% of the stellar disc and cooler by 1200 K compared to the unspotted photosphere are necessary to explain the 1985 light curve. The level of activity was decreasing since then and the star seems to be passing through a phase of minimum activity. Simultaneous spectroscopic and photometric observations over at least one rotation period of the star are essential to investigate the nature of activity on HD 127 535.

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