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The active RS Canum Venaticorum binary II Pegasi

III. Chromospheric emission and flares in 1994–1996*

S.V. Berdyugina, I. Ilyin, and I. Tuominen

Astronomy Division, University of Oulu, P.O. Box 3000, FIN-90401 Oulu, Finland

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Abstract. We analyse observations of the very active RS CVn-type star II Peg carried out simultaneously in chromospheric and photospheric lines in 1994–1996. We describe the correlation of the strength of the He I D_3, Ca II K and Ca II 8498 Å emissions with the spot position on the stellar disk. A two-component structure is suggested in the chromosphere of II Peg, similar to that in the corona: nonvariable component (cool plages) with constant contribution to the line emission and variable, active one (hot plages) showing a growth of its activity during 1994–1996. The active component is related to the spots seen in the photosphere.

Two subsequent flares on July 19–23, 1995 were observed in the He I D_3 and Ca II K and 8498 Å lines showing strong *narrow red-shifted* emissions. The development of the flares took a few hours and decay lasted several days. At the maximum of the flaring, in addition to the narrow components, *broad blue-shifted* emissions appeared in He I and Ca II K and in the cores of many strong absorption lines. The broad components are attributed to the process of the explosive evaporation from the low chromosphere. The amount of energy released in different lines is determined. From the radial velocity curve of the He I emission the location of the radiating matter is deduced. It appears to be related to the largest active region which is seen in the stellar image. The flare occurred concurrently with the break of the extended group on two well separated spots. On October 26, 1996 another flare was observed in three spectra, as narrow emissions in the He I and Ca II 8498 Å lines but without development in other lines. It probably was a late stage of the flare decay.

Key words: stars: activity – stars: chromospheres – stars: flare – stars: individual: II Peg

1. Introduction

II Peg (HD 224085) is one of the most active RS CVn binaries showing remarkable photometric variability, Hα and Ca II H&K emission, UV, radio, and soft X-ray radiation. This activity is attributed to the primary, rather than to the unseen secondary, and indicates its active photosphere, chromosphere, and corona. Our analysis of the optical spectrum of the star has revealed that the primary is an old-disk K2 IV star which has evolved to the base of the Red Giant Branch. The secondary is thought to be a low-mass main-sequence M-dwarf (Berdyugina et al. 1998a, Paper 1). Stellar images of the primary show a long-lived spot structure in its photosphere (Berdyugina et al. 1998b, Paper 2). The spots migrate in the orbital reference frame with a constant rate and comprise two active longitudes which are active by turns and, thus, determine a magnetic cycle of 9.3 years, (Berdyugina & Tuominen 1998).

Early spectroscopic observations of the star have revealed strong emissions in the Ca II H&K and Hα lines (Rucinski 1977). The emission in Hα was noticed to be asymmetric with an enhanced blue wing and strongly correlated with spot visibility. It is more intense when the spot regions are on the visible hemisphere (Bopp & Noah 1980; Vogt 1981). The same spatial correlation has been observed for emission lines from the high-temperature transition region and chromosphere in the UV (Rodonó et al. 1987; Byrne et al. 1987). This has been interpreted as evidence of large magnetic loops overlying spot areas and forming plages in the outer atmosphere. Recently published monitoring observations in chromospheric lines (Byrne et al. 1995, 1998; Montes et al. 1997) have shown that the star in its quiescent (out-of-flare) state is continually variable. The profile of Hα has exhibited broad emission wings which suggest complicated velocity fields in the deep chromosphere with both upward and downward motions. It was suggested also that the broad wings of Hα are the result of microflaring in the chromosphere since they are reminiscent of broad wings of transition region lines in solar and stellar explosive events.

II Peg is a high-rate flaring star, especially in the UV and in X-rays. From the far UV and X-ray spectrum a bimodal temperature structure of the quiescent corona of II Peg was inferred (Tagliaferri et al. 1991, Mewe et al. 1997). During a flare, the cool component of the corona seems to show the same parameters as the quiescent spectrum, while the hot component increases considerably both in emission measure and in temperature. By studying the decay of a flare, Mewe et al. (1997) found that in comparison with flares on other types of stars the flare on II Peg had a very long duration, large associated vol-

Send offprint requests to: S.V. Berdyugina (sveta@ukko.oulu.fi)

* Based on observations collected at the Nordic Optical Telescope (NOT), La Palma, Spain

ume and relatively low density. Evidence for highly extended (probably loop-like) flaring structures also was found by Doyle et al. (1992). Another long-lasting flare in X-rays was reported by Tagliaferri et al. (1991): the development of the flare took a few hours, while the decay lasted about two days. The total radiative loss from the chromosphere and transition region during such flares can be up to $3{\cdot}10^{35}$ erg (Doyle et al. 1989a, 1989b; Tagliaferri et al. 1991).

Flares on II Peg in the optical spectral lines have been reported several times (Bopp & Noah 1980; Huenemoerder & Ramsey 1987; Huenemoerder et al. 1990; Mohin & Raveendran 1993; Byrne et al. 1995, 1998; Montes et al. 1997). Sudden enhancements of the Hα and Ca II lines and development of the emission in the He I lines are always attributed to flare-like events. The ratio of the emission of Hα to that of Hβ is found to be a good indicator of a flare: in quiescent state it is similar to the ratio in solar prominences, while during line enhancements it decreases toward values more typical of solar flares. Analogously, absorption in the He I lines is attributed to plages, while detection of any emission is immediately connected to flares, as in the Sun.

There are a few reports of flares detected in the optical U-band (Doyle et al. 1991; Mathioudakis et al. 1992; Henry & Newsom 1996), while no flares were observed during monitoring by Byrne et al. (1994). This suggests that II Peg can be in states of different flare activity.

In our paper we present additional evidence of the spatial correlations of the quiescent emission in the Ca II K, Ca II 8498 Å and He I D_3 lines with the photospheric spots seen in the stellar images and photometric light curves during 1994–1996 (Paper 2). Also, we report on two optical flares observed spectroscopically on July 19–23, 1995 and October 26, 1996. For the first flare we present unique data acquired from a large spectral region and lots of spectral lines.

2. Observations

Observations were carried out in 1994–1996 with the SOFIN échelle spectrograph fed by the 2.56 m Nordic Optical Telescope (NOT) on La Palma, Canarias. During three seasons, July 1994, July 1995, and August 1996, a total of 58 spectra in the 5500–8500 Å region have been obtained. These spectra have been reduced and used for determining the orbital and stellar parameters of the star in Paper 1 and for surface imaging in Paper 2. Dates, phases and quality of the observations have been given in those papers. Additionally, 20 spectra in the 3850–4500 Å region were obtained in 1995 and 1996. A catalog of the observations is given in Table 1. Three lines, Ca II K, Ca II 8498 Å, and He I D_3, are available for the analysis of the chromospheric emission, though because of the orbital motion of the star and the chosen échelle frame position, the Ca II 8498 Å line was observed at the very edge of the CCD at certain phases. Therefore, only a peak intensity can be measured for this line over the period.

The spectral resolving power achieved in the spectra is from 75000 to 83000 for blue and red regions, respectively. The signal-to-noise ratio of the spectra increases from 20 to 150 for the wavelengths from 3850 Å to 4500 Å and was 200–300 for redder wavelengths. The reduction of the spectra is described in Paper 1. Quasi-simultaneous photometry of the star was presented in Paper 2. All observations are phased according to the orbital ephemeris from Paper 1, which is used throughout this paper:

$$\mathrm{T_{conj}} = \mathrm{HJD}\,2449582.9268 + 6.724333E \qquad (1)$$

with the primary in back at phase zero.

Two flare events have been recorded on July 19–23, 1995 and October 26, 1996. Emissions appeared during the flares were obtained from the observed spectra by subtracting the quiescent spectra observed one rotation before. Unfortunately, no simultaneous photometry for the flares is available.

Table 1. Spectroscopic observations in the 3850–4500 Å region.

Date	HJD 2400000+	Phase	Date	HJD 2400000+	Phase
	1995			*1996*	
12/07	49910.7138	0.7467	29/07	50293.7250	0.7058
13/07	49911.7245	0.8966	31/07	50295.7073	0.0003
15/07	49913.7082	0.1917	02/08	50297.7366	0.3024
16/07	49914.7189	0.3421	03/08	50298.7369	0.4511
17/07	49915.7190	0.4909	04/08	50299.7421	0.6004
18/07	49916.7154	0.6390	24/10	50381.4590	0.7531
20/07	49918.6723	0.9300	25/10	50382.4685	0.9029
22/07	49920.7183	0.2344	26/10	50383.4302	0.0458
			27/10	50384.4497	0.1975
			28/10	50385.5085	0.3549
			29/10	50386.4705	0.4978
			31/10	50388.4265	0.7888

3. The out-of-flare chromospheric emission

3.1. The Ca II lines

The Ca II K and IRT Ca II 8498 Å lines are the traditional spectral probes of the low chromosphere. They show distinct variations with the spot visibility, especially in the year 1996 (Fig. 1). The variations are similar to those usually seen in Hα: the emission is more intense when the light curve is near minimum, in other words, when the spotted regions are on the visible hemisphere. As was mentioned, such a correlation suggests the presence of plages in the outer atmosphere overlying the spots. The maximum of the out-of-flare emissions in the lines has increased since 1995, while the minimum emission is at the same level for both years. This can be caused by an increase in the amount of material above the spots, in the lower chromosphere, while the nonactive hemisphere of the star has not changed its emission during the period of 1995–1996.

3.2. The He I D_3 line

This line is formed in the upper chromosphere. Nevertheless, it shows similar behaviour to the Ca II lines. When spots are becoming visible, the helium line is gradually transforming from

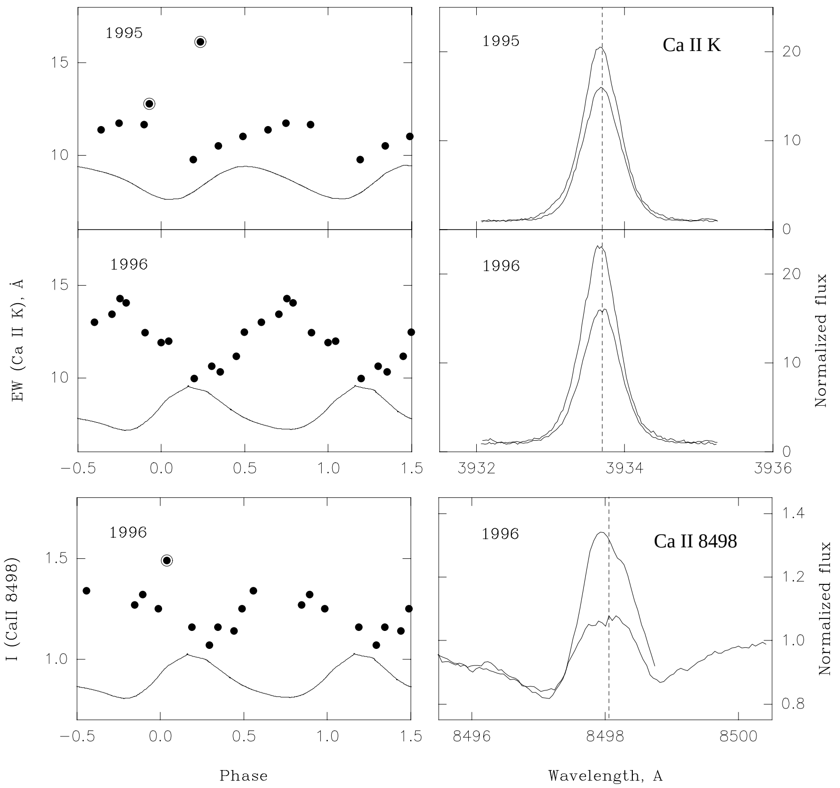

Fig. 1. *Left panels:* Equivalent width variations of the Ca II K line in 1995–1996 and central intensity variations of the Ca II 8498 Å line in 1996. Emphasized dots are the flares on July 19–23, 1995 and October 26, 1996. The curves below the dots are the V-band variations for the seasons. Phases have been calculated with the orbital ephemeris given by Eq. 1. *Right panels:* The profiles of the Ca II lines with the maximum and minimum equivalent widths observed at the seasons. Vertical dashed lines indicate the rest wavelengths in the frame of the primary.

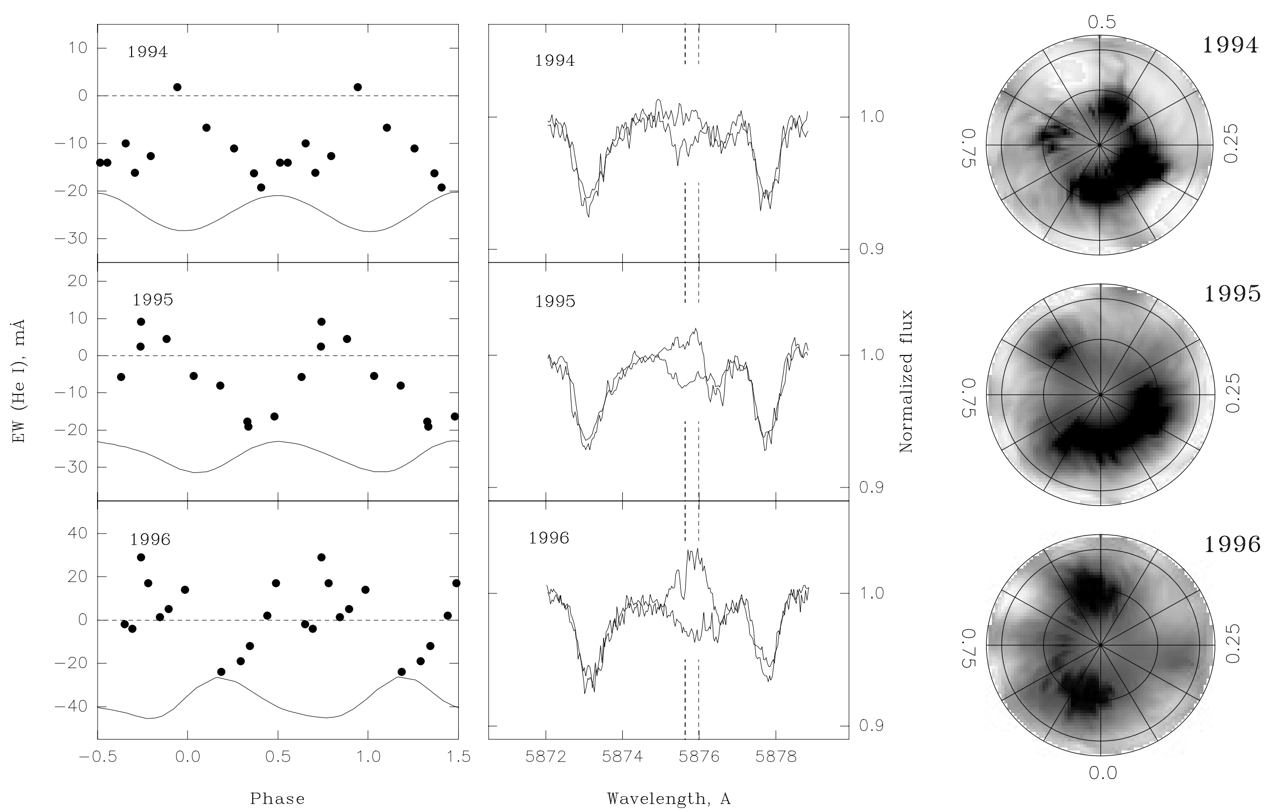

Fig. 2. Same as Fig. 1 for the He I D_3 line in 1994-1996. The flares on July 19–23, 1995 and October 26, 1996 are out of scale. Negative values of equivalent widths mean that the line was observed in absorption, while positive values indicate the line to be in emission. The emission in the line has been increasing during 1994–1996, while the absorption was at the same level. Three images of II Peg in the pole-on projection are shown for the three years from Paper 2.

absorption to emission (Fig. 2). As was mentioned, an absorption in the line is always attributed to plages, while any emission is considered as a primary indication of flares. However, our observations show that even in the quiescent, out-of-flare state the He I D_3 line can appear in emission which fills the absorption up to 30 mÅ above the continuum (about 50 mÅ in total). This emission indicates very hot plasma in the upper chromosphere, above the spots and low-chromosphere plages which are seen in the Ca II lines. The stratification is reminiscent of a large magnetic loop overlying the spots. The quiescent emission in the He I D_3 line increased significantly during 1994–1996, as seen in Fig. 2. This, again, suggests a growth in volume of the hot matter in the upper chromosphere. The amount of the absorption corresponding to the nonactive hemisphere of the star was stable during 1994–1996, about 20 mÅ.

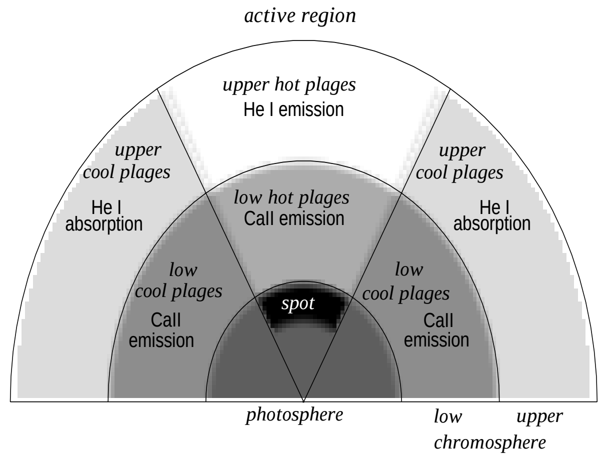

Fig. 3. The structure of the active region in the atmosphere of II Peg as seen from the stellar images and He I D_3 and Ca II K emissions.

3.3. The structure of active regions

As the observations of the chromospheric indicators were carried out simultaneously with the photospheric lines, from which the surface images of the star were obtained (Paper 2), we have the opportunity to study the radial structure of the active regions from the photospheric level to the upper chromosphere. In Fig. 2 three stellar images are shown for July 1994, July 1995, and October 1996 from Paper 2, which are relevant for the present observations. In 1994 and 1995 the largest active region is seen in the phase intervals of 0.9–0.25 and 0.8–0.25, respectively. It has moved in phase during the year because of the difference between the orbital and spot rotation periods, as was discussed in Paper 2. The maximum emission in the chromospheric lines occurs at the phases 0.9 and 0.8 in 1994 and 1995, respectively, corresponding to the edge of the active region. This suggests that a gross amount of the active plasma was concentrated in the part of the active region, near its edge. This part at the phase 0.9 has survived to the end of 1996 at all three levels – photosphere, low chromosphere, and upper chromosphere. The other part of the active region, with no significant matter in the chromosphere, near the phase ∼0.2, migrated to the phase ∼0.5 during only two months, after the strong flare on July 19–23, 1995 (see Sect. 4.4). The resulting active region near the phase 0.5 survived to the end of 1996 and accumulated a significant amount of the matter in the chromosphere. This has caused the increase of the emission in the Ca II K and He I D_3 lines in 1996. The two active regions of 1996, near the phases 0.9 and 0.5, are seen in the helium emission as two local maxima overlying the broad photometric minimum (Fig. 2).

Summarising the above discussion, we suggest that there are two temperature components in the chromosphere of II Peg (Fig. 3). First, an *active* component, which consists of the plages overlying the spots. In the upper chromosphere it is hot and dense enough to give a moderate emission in helium lines. Second, a *nonactive*, cool component, which is the rest of the chromosphere of lower temperature. It results in an absorption in helium lines. The higher temperature of the plages in the active component arises from the additional, magnetic heating in the magnetic loops connected to the spots. The nonactive component seems to be stable for years, while the active component is changeable at various time scales: months, days, and hours. The two-temperature structures are observed at all levels of the atmosphere of II Peg: spots and unspotted surface in the photosphere, hot and cool plages in chromosphere, hot and cool components in the corona (e.g. Mewe et al. 1997). Considering the active and nonactive components in the atmosphere, the former includes spots and hot components of the chromosphere and corona, while the latter consists of the other parts. Therefore, the temperature gradients in the components are rather different – it is much steeper in the active component. This should be taken with caution when modeling the outer atmosphere of II Peg and other active stars by fitting observed line emissions.

4. The flare on July 19–23, 1995

4.1. The upper-chromosphere line He I D_3

The flare started on July 19, 1995 and was noticed first in the He I D_3 line which appeared as a strong, asymmetric, red-shifted, narrow emission (Fig. 4). The emission was seen for 5 days until the end of the observing run (July 23, 1995), even in the low S/N spectrum on July 21 (not shown in the figure). The maximum of the emission was reached on July 22, when in addition to the narrow component, a broad blue-shifted component was seen. At that moment, the two-component emission was observed in the Ca II K and Ca II 8498 Å lines as well as in cores of many absorption lines (see Sect. 4.2). On July 23, all lines had returned to their quiescent shapes, except He I which still showed both emission components, although reduced in strength. The energy released in the flare in the helium line is presented in Table 2.

The asymmetric narrow component of the helium emission is well fitted by two Gaussians of different intensities and FWHM=25–30 km s^{-1} (Fig. 4). These Gaussians are interpreted as the components of the resolved ("doublet") components of the line. They are both red-shifted in respect to the rest wavelengths of 5875.62 Å and 5875.99 Å. The broad, blue-shifted component of FWHM=80 km s^{-1} is attributed to the

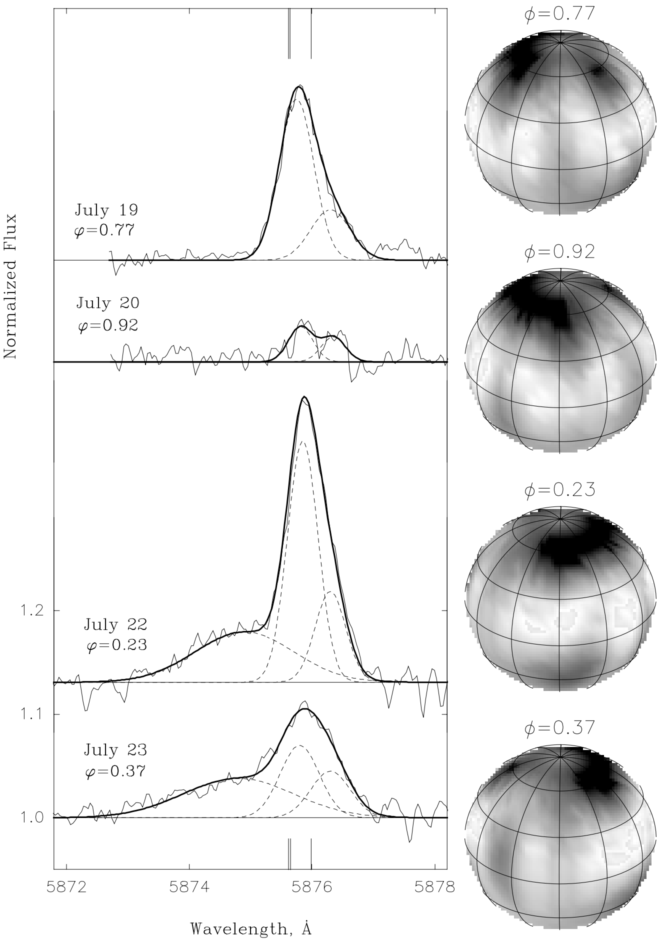

Fig. 4. Profiles of the He I D_3 line during the flare on July 19-23, 1995 and the relevant stellar image showing the spot distribution on the visible hemisphere from Paper 2 at the moments of the observations of the flare. In the profiles: a thin solid line shows the observations, dashed lines are the Gaussian components fitted to the profiles, and a thick solid line is the sum of the Gaussians. Vertical lines show the rest wavelengths of the helium triplet. The profiles are shown in the rest frame of the primary.

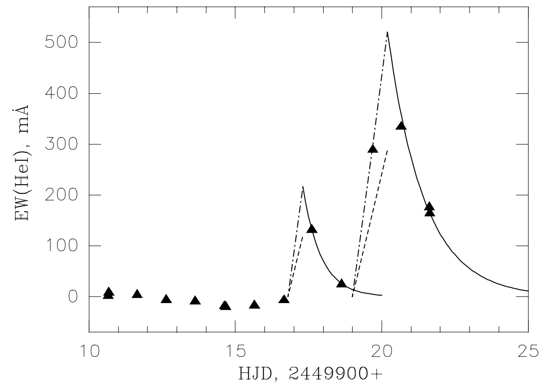

Fig. 5. The equivalent widths of the He I D_3 line versus time. Observations are shown by triangles. The dashed line is the flare development rate of 10 mÅ/h estimated from Huenemoerder et al. (1990), and the dash-dotted line is that of 18 mÅ/h estimated from Montes et al. (1997). Exponential decays of the flares are shown by the solid line: $e^{-1.6t}$ for the first flare and $e^{-0.8t}$ for the second one (t is in days).

Table 2. The energy released in the flare on July 19–23, 1995 in the He I D_3 and Ca II lines caculated with d=42.3 pc (π=0.″02362). ΔT is the exposure time.

Date	ΔT (s)	EW (Å)	F (erg s^{-1}cm^{-2})	E (erg s^{-1})
		He I D_3		
19/07/1995	2715	0.132	$4.47\cdot10^{-13}$	$0.96\cdot10^{29}$
20/07/1995	3600	0.025	$8.46\cdot10^{-14}$	$0.18\cdot10^{29}$
21/07/1995	840	0.290	$9.82\cdot10^{-13}$	$2.11\cdot10^{29}$
22/07/1995	3600	0.335	$1.13\cdot10^{-12}$	$2.42\cdot10^{29}$
23/07/1995	1500	0.177	$5.99\cdot10^{-13}$	$1.28\cdot10^{29}$
23/07/1995	1500	0.165	$5.58\cdot10^{-13}$	$1.20\cdot10^{29}$
		Ca II K		
20/07/1995	3610	1.10	$1.49\cdot10^{-12}$	$3.19\cdot10^{29}$
22/07/1995	4200	6.43	$8.70\cdot10^{-12}$	$1.86\cdot10^{30}$
		Ca II 8498 Å		
22/07/1995	3600	0.477	$1.67\cdot10^{-12}$	$3.58\cdot10^{29}$
23/07/1995	3000	0.255	$0.89\cdot10^{-12}$	$1.91\cdot10^{29}$

first, stronger, narrow component. The relative intensity of the narrow Gaussians changes during the flare. This can be caused by evolving excitation conditions in the emitting matter.

It was noticed that flares on II Peg have a very long duration in comparison with flares on other types of stars (e.g. Mewe et al. 1997). The long time scale is determined by a low density and a large volume of a flare. To see the development of the flare, we plot the equivalent widths of the He I line versus time in Fig. 5. Actually, two subsequent flares were possibly observed: on July 19–20 and July 21–23. Both flares developed during a few hours, while their decays have taken about 1.5 days for the first flare and even more, probably about 3 days, for the second flare. Such a strong emission in the He I line has never been observed in II Peg or other active stars. Previously reported equivalent widths of the emission in the He I D_3 line observed in II Peg are more than a factor of two smaller. All the emissions have been interpreted as indications of flares, although only two of them have been seen as developing, in November 1988 (Huenemoerder et al. 1990) and September 1995 (Montes et al. 1997). From the two papers we estimated the rates of increase of the helium emission of 10 mÅ/h and 18 mÅ/h, respectively. The second rate suits our data better, within uncertainties. Assuming an exponential decay of the flare, we found that the first flare faded out as fast as $e^{-1.6t}$, while the second, stronger one decreased slower, as $e^{-0.8t}$ (t is in days). The latter is probably caused by the slower decay of the broad component, as seen from the profiles. A total radiative loss in the helium line during the flare is about $8\cdot10^{34}$ erg.

4.2. The low-chromosphere and upper-photosphere lines

Emission in the Ca II lines significantly increased during the flare. We have observed only two phases in Ca II K and two phases in Ca II 8498 Å. The behaviour of the emissions correlates well with that of the helium line. Two components – broad

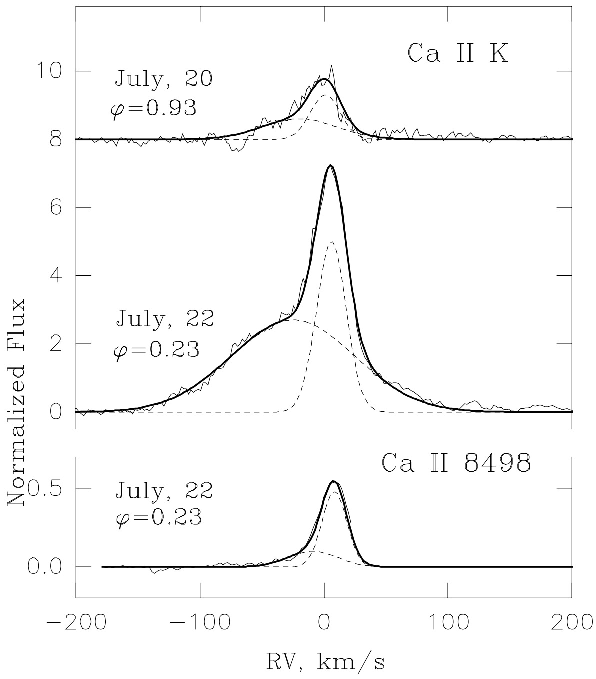

Fig. 6. Profiles of the Ca II K and 8498 Å lines during the flare on July 19–23, 1995. The notation is the same as in Fig. 4. The profiles are shown in the rest frame of the primary.

blue and narrow red – are distinctly seen in the Ca II emissions at the maximum of the flare (Fig. 6). The energy released during the flare in the calcium lines is presented in Table 2.

At the maximum of the flare, emission components appear in the line cores of very strong absorption lines and also in high-excitation lines, which are formed in the low chromosphere and upper photosphere. A list of the lines along with the parameters of the Gaussian components fitted to the profiles is presented in Table 3. With a semi-empirical chromosphere model of II Peg recently developed by Short et al. (1998) we have calculated the LTE depths of formation of the line cores which showed the emissions (Fig. 8). Those lines whose cores are formed in the low chromosphere show distinct two-component emissions. Their profiles are displayed in Fig. 7. The average FWHM and RV of the blue components are of 32 km s^{-1} and –6 km s^{-1}, respectively; those of the red components are of 12 km s^{-1} and +8 km s^{-1}, respectively. The weaker absorption lines whose cores are formed in the upper photosphere show weaker, single-component emissions with FWHM=12 km s^{-1} and RV=7 km s^{-1}, on average. Only a limited number of them is given in Table 3.

As seen from Fig. 8, there is a probable decrease in the released energy when going into deeper layers of the atmosphere. The appearance of the strong red-shifted emission component in He I on July 19 signals that particle beams have rushed into the chromosphere. They heated the atmosphere as deep as $\log\tau_{5000} < -1$ and caused the collisionally excited, red-shifted emissions in the line cores. This downflow was seen during at least 5 days in the helium line, 2–3 days in the Ca II lines, and at least one day in other lines. A similar downflow was observed in Mg II h&k during a flare on II Peg in 1983 (Doyle et al. 1989b) and also in flares on other RS CVn stars. When the beams are rushed into the dense chromosphere, they heat its matter, and the heated plasma fills the flare volume through the process of chromospheric evaporation (e.g. Haisch et al. 1991). Such upward turbulent motion is observed as broad, blue-shifted emission components in many lines, and it was seen at least two days in He I and once in other lines. The evaporation comes from the low chromosphere, $\log\tau_{5000} < -3$.

One must note that broad blue-shifted components in the spectrum of II Peg were previously observed only in the profiles of the Mg II h&k lines at the maximum of the flare in 1983 (Doyle et al. 1989b). In other active stars they have been occasionally observed in Hα (HK Lac, RS CVn-type binary, Bopp & Talcott 1980), Ca II H&K and blue Balmer lines (AT Mic, M-dwarf, Gunn et al. 1994), He I D_3, Na I D, Fe II and Si II (S CrA and T Tau, TTS, Hamann & Persson 1992; Hartmann 1982). In all the cases the emissions were observed as rare transient phenomena with lifetimes from 15 min to 2 days.

Our observations relate solely the appearance of broad blue-shifted components in permitted emission lines with the process of chromospheric evaporation during the strongest flares. Also, we show that in active stars the explosive evaporation can arise from the low chromosphere level, while in solar flares it comes from the upper chromosphere and is seen only in ultraviolet and X-ray radiation (e.g. Fisher 1987).

4.3. The location of the flare

Since the He I emission was observed at four orbital phases during the flare and six phases in the quiescent state, its orbital motion can be used to estimate probable location of the flare. Varying the γ-velocity of the orbit obtained from the photospheric lines (Paper 1), the best fit to the He I velocities was found (Fig. 9). One can see that the amplitude of the orbital motion of the He I emission is well fitted by that of the photospheric lines, only γ-velocities are different. Since the amplitude value is determined by the distance to the mass centre of the system, the flare origin has to be on the primary of II Peg. In other words, it should either overtake the whole chromosphere or be in the plane crossing the mass centre and visible pole of the primary and preserving its distance to the mass centre of the system due to (quasi)synchronous rotation. The latter case is the most probable since a flare is presumed to be a local event. Also, we stress that the narrow components in He I observed in the flare are red-shifted *at all orbital phases*, for more than half a period. This suggests that the emitting matter was located somewhere above the pole. Taking into account that (i) there was a large active region near the pole, (ii) the flare has been observed at the phases when the region was crossing the visible hemisphere (Fig. 4), and (iii) the quiescent helium emission was connected to the spots, we suggest that the flare likely arose close to the pole and next to the active region observed in 1995. The flare appears to be related to the active component of the chromosphere which is seen from the quiescent helium and calcium emissions.

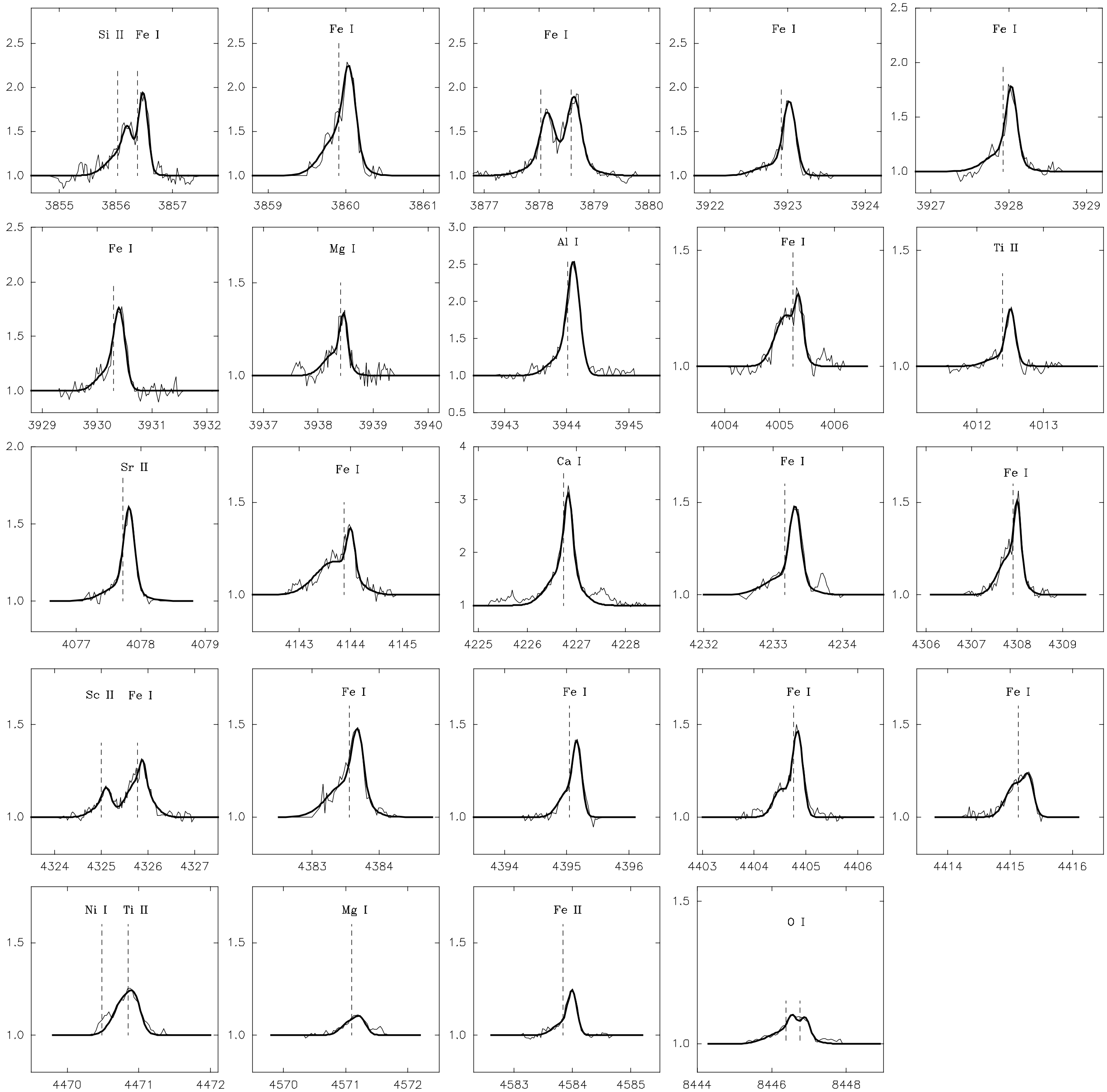

Fig. 7. Profiles of the emissions that appeared at the cores of strong and high-excitation lines at the maximum of the flare, on July 22, 1995.

4.4. *The post-flare spot distribution*

The connection of the flare to the largest active region is also favoured by the subsequent observations of the star. It appears that on July 19, 1995 II Peg experienced a heavily active flaring stage. One rotation before (during 7 days) the star was in its normal, quiescent state. Then, we observed 5 days of flaring which, obviously, has not finished on July 23. Two weeks later, on August 5–9, 1995, additional flare activity was recorded by EUVE (Osten et al. 1998 and private communication). Then, one month later, on September 13–14, 1995, a new flare was observed in the helium line and Hα (Montes et al. 1997).

We suggest that this strong flare activity, started on July 19, 1995 and observed during two months, occurred concurrently with the radical change of the spot structure on the stellar surface. In Fig. 10 we display two surface images and two light curves from Paper 2 corresponding to July 1995 (before the flare) and October 1995 (after the flare). The break of the large active region into two smaller ones after the heavy flaring is well seen in the images. A clear development of the secondary

Table 3. Parameters of the emissions observed at the maximum of the flare on July 22, 1995: equivalent widths EW (Å), maximum intensity I, full width at half maximum FW (km s^{-1}) and radial velocity RV (km s^{-1}).

Two-component emissions									*Some of the single-component emissions*					
λ,Å	Elem.	EW	*Broad component*			*Narrow component*			λ,Å	Elem.	EW	*Narrow component*		
			RV	FW	I	RV	FW	I				RV	FW	I
3856.018	Si II	:	:	:	:	13.3	12.5	0.30	3858.303	Ni I	0.125	7.9	18.6	0.42
3856.377	Fe I	0.344	–20.2	39	0.28	8.1	12.4	0.85	3865.527	Fe I	0.067	6.4	15.6	0.27
3859.916	Fe I	0.403	–1.2	31	0.45	10.2	12.5	0.90	4071.530	V I	0.056	7.0	13.2	0.25
3878.028	Fe I	0.149	:	:	:	8.5	18.6	0.50	4071.745	Fe I	0.056	8.1	11.8	0.28
3878.584	Fe I	0.458	–18.1	62	0.25	4.3	18.6	0.70	4092.394	Co I	0.036	4.9	11.8	0.18
3922.919	Fe I	0.215	–9.1	30	0.12	7.9	12.2	0.78	4167.277	Mg I	0.036	9.8	13.0	0.16
3927.929	Fe I	0.198	–2.2	31	0.17	8.2	10.6	0.65	4224.172	Fe I	0.025	10.5	12.8	0.11
3930.303	Fe I	0.256	–7.9	30	0.19	7.9	15.2	0.65	4225.460	Fe I	0.030	14.0	11.4	0.15
3933.664	Ca II	6.430	–25.0	100	2.70	6.0	24.4	5.00	4227.434	Fe I	0.054	5.9	12.8	0.24
3938.406	Mg I	0.103	–8.1	30	0.12	4.8	10.6	0.25	4246.835	Sc II	0.029	9.5	12.8	0.13
3944.016	Al I	0.473	–8.8	30	0.25	7.3	15.2	1.40	4300.049	Ti II	0.065	9.0	12.6	0.29
4005.250	Fe I	0.144	–9.7	30	0.22	8.2	10.4	0.20	4301.927	Ti II	0.038	9.4	11.2	0.19
4012.385	Ti II	0.058	–2.6	30	0.04	9.3	10.4	0.22	4303.229	Co I	0.040	6.2	11.2	0.20
4077.722	Sr II	0.168	–2.4	38	0.10	7.2	11.8	0.52	4305.714	Sc II	0.025	12.2	12.6	0.11
4143.875	Fe I	0.209	–14.1	52	0.18	9.1	11.6	0.24	4312.869	Ti II	0.021	8.0	9.8	0.12
4226.734	Ca I	0.848	–0.3	42	0.70	6.8	12.8	1.45	4314.087	Sc II	0.025	7.0	8.4	0.17
4233.168	Fe II	0.147	–1.3	38	0.10	10.6	11.4	0.40	4314.304	Fe II	0.019	9.9	9.8	0.11
4307.911	Fe I	0.195	–5.6	33	0.21	6.9	11.2	0.35	4314.800	Ti I	0.044	4.9	11.0	0.22
4324.999	Sc II	0.055	–3.4	28	0.05	8.3	13.8	0.12	4314.980	Ti II	0.052	8.9	12.4	0.23
4325.772	Fe I	0.145	–0.1	34	0.20	8.2	9.8	0.12	4399.772	Ti II	0.019	8.4	9.6	0.11
4383.555	Fe I	0.195	–5.1	36	0.18	8.6	12.4	0.35	4470.144	Mn I	0.022	2.2	10.8	0.11
4395.038	Ti II	0.106	–2.6	19	0.13	9.0	9.6	0.35	4481.134	Mg II	0.017	5.4	9.4	0.10
4404.760	Fe I	0.168	–16.3	20	0.15	5.4	13.6	0.45	4481.327	Mg II	0.032	14.3	10.8	0.16
4415.130	Fe I	0.064	–3.4	20	0.08	11.6	10.8	0.17	5857.458	Ca I	0.012	4.9	10.2	0.05
4470.854	Ti II	0.095	–3.6	20	0.20	6.4	10.6	0.10	6162.180	Ca I	0.033	6.1	12.8	0.08
4571.100	Mg I	0.040	0.0	20	0.08	9.8	10.4	0.05	6169.043	Ca I	0.012	6.6	12.6	0.04
4583.835	Fe II	0.066	–2.3	20	0.06	10.8	10.4	0.22	6169.565	Ca I	0.011	6.1	9.8	0.04
5875.620	He I	0.335	–36.8	82	0.05	11.7	25.6	0.24	6191.189	Ni I	0.020	7.9	13.6	0.06
5875.989	He I	:	:	:	:	15.9	25.6	0.07	6191.568	Fe I	0.020	6.2	15.6	0.06
8446.384	O I	0.048	–6.5	28	0.03	5.9	8.6	0.06	6347.098	Si II	0.011	10.0	18.0	0.02
8446.755	O I	0.051	–5.5	28	0.03	5.1	8.6	0.07	6371.357	Si II	0.006	6.7	9.4	0.03
8498.052	Ca II	0.477	–8.7	40	0.10	8.3	19.8	0.48	6545.900	Mg II	0.008	6.5	9.0	0.03
									6717.688	Ca I	0.014	5.5	14.2	0.04
									7148.157	Ca I	0.015	5.8	9.2	0.05

minimum in the light curve confirms this event. Considering the solar case, large flares erupt near emerging magnetic flux regions, when old and new magnetic structures interact with one another, and the level of flare activity can remain high during many days. Similarly, on two RS CVn type stars, HK Lac (Catalano & Frasca, 1994) and HR1099 (Zhai et al. 1994), new spotted regions were noticed in light curves after strong optical flares. Our results give another clear evidence for the connection between a flare eruption and changes in the surface spot structure on other stars but the Sun.

5. The flare on October 26, 1996

The flare was seen as a narrow emission in He I D_3 and an increased emission in Ca II 8498 Å. As in the flare in July 1995, the helium emission was red-shifted and asymmetric, with two narrow components in the profile (Fig. 11). No broad components have been observed. A decrease of the emission in both lines during two hours is seen well in three subsequent exposures. The energy released in the flare is presented in Table 4. Other lines retained their quiescent shapes. The most probable explanation of the observed emission is a late stage of the flare decay.

6. Conclusions

From the analysis of the simultaneous observations of the very active RS CVn-type star II Peg, carried out in chromospheric and photospheric lines in 1994–1996, the following results have been obtained:

1. A strong correlation of the strength of the He I D_3, Ca II K and Ca II 8498 Å emissions with the spot position on the stellar disk has been revealed. An analysis of this correlation has suggested a two-component structure in the chromosphere of II Peg, similar

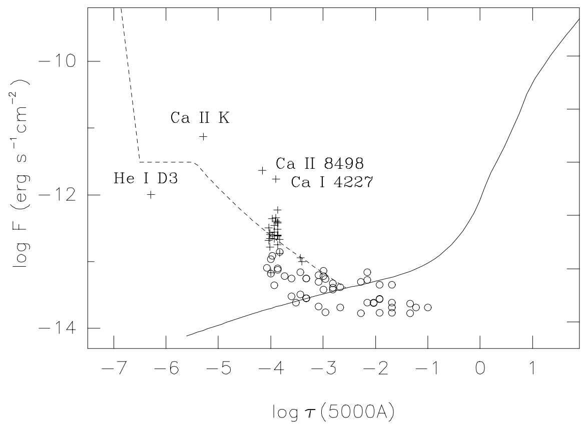

Fig. 8. Fluxes of the emissions that appeared in the line cores at the maximum of the flare on July 22, 1995 versus optical depths of formation of the line cores, τ_{5000}, calculated from the LTE model with $T_{\rm eff}$=4600 K, log g=3.2, [M/H]=-0.4 (solid line) updated by the semi-empirical chromosphere model (dashed line, Short et al. 1998). Crosses are the emissions with broad and narrow components, circles show the emissions with narrow components only.

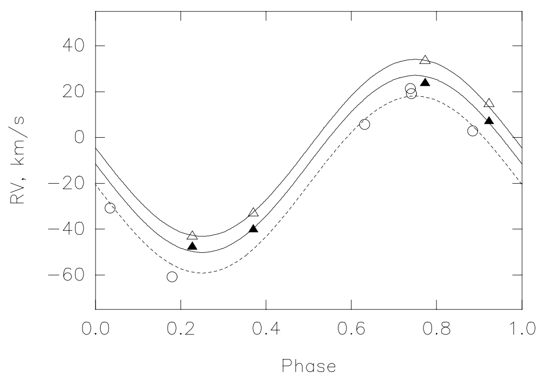

Fig. 9. Radial velocities of the emission in He I in 1995: circles are the quiescent emission, triangles are the two Gaussians fitted to the narrow components of the emission observed during the flare on July 19–23, 1995. The orbit deduced from the photospheric lines is shown with dashed lines. The best fits to the He I velocities are shown with solid lines.

to that in the corona. An *active* component which consists of the plages overlying the spots is hot and dense enough to give a moderate quiescent emission in helium lines from the upper chromosphere. A *nonactive*, cool component, which is the rest of the chromosphere of lower temperature, results in a quiescent absorption in helium lines. The nonactive component is found to be stable for years, while the active component is changeable on various time scales. It increased in emission during 1994–1996 indicating the growth of the general activity level of II Peg.

2. Two subsequent flares in July 1995 were observed. The first flare, on July 19–20, 1995 was identified in the He I D_3 line which appeared as an asymmetric, red-shifted, narrow emission. Some excess of the emission in the Ca II K line was seen as well. The development of the flare took a few hours and decay lasted two days. The subsequent flare, on July 21–23, 1995 was the strongest flare ever observed in the optical lines. At the the

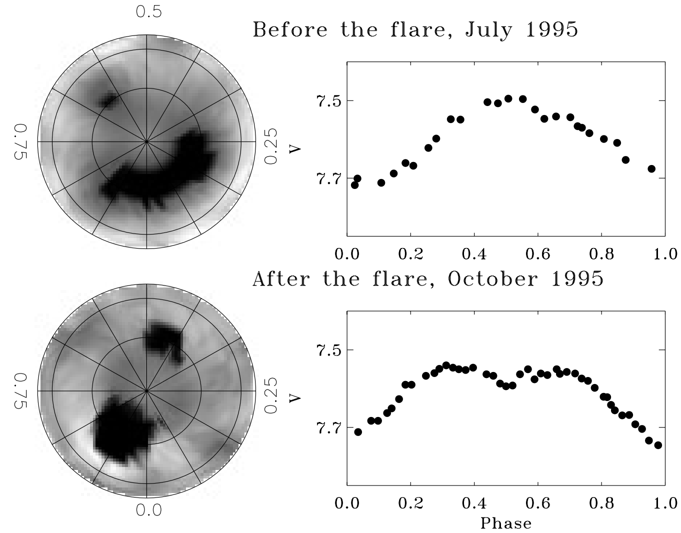

Fig. 10. The surface images and light curves for the times before and after the strong flare on July 19–23, 1995. As is suggested, the flare occured concurrently with the radical change of the spot structure on the stellar surface.

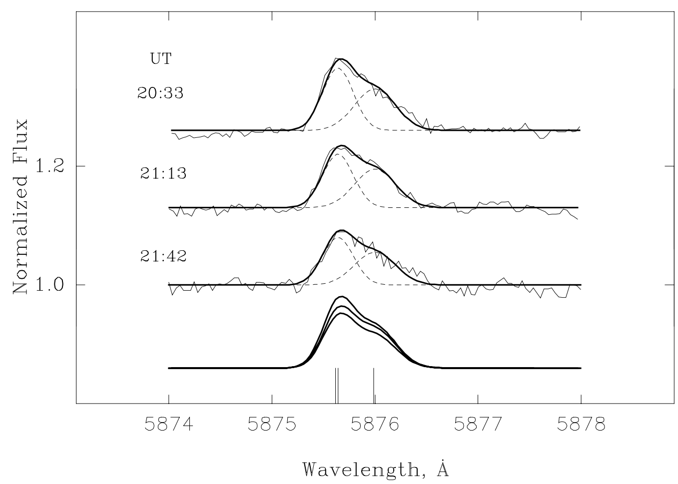

Fig. 11. Profiles of He I D_3 on October 26, 1996 (see the notation in Fig. 4.

Table 4. The energy released in the flare on October 26, 1996 in the He I D_3 and Ca II 8498 Å lines caculated with d=42.3 pc (π=0.″02362). ΔT is the exposure time.

HJD 2450000+	ΔT (s)	EW (Å)	F (erg s^{-1}cm^{-2})	E (erg s^{-1})
		He I D_3		
383.3612	2400	0.077	$2.72\cdot10^{-13}$	$5.83\cdot10^{28}$
383.3846	2400	0.068	$2.40\cdot10^{-13}$	$5.15\cdot10^{28}$
383.4092	960	0.058	$2.05\cdot10^{-13}$	$4.31\cdot10^{28}$
		Ca II 8498 Å		
383.3612	2400	0.170	$5.87\cdot10^{-13}$	$1.26\cdot10^{29}$
383.3846	2400	0.164	$5.67\cdot10^{-13}$	$1.22\cdot10^{29}$
383.4092	960	0.156	$5.40\cdot10^{-13}$	$1.16\cdot10^{29}$

maximum of the flare, in addition to the narrow emission components, broad blue-shifted emissions appeared in He I and Ca II K and in the cores of many strong absorption lines. The narrow, red-shifted emissions have been attributed to downflows in the active region, and the broad, blue-shifted emissions have been regarded as indications of upward motions of heated plasma within the flare volume through the process of the explosive chromospheric evaporation.
3. From the radial velocity curve of the He I emission the location of the radiating matter has been deduced. It appeared to be related to the largest active region which was seen in the stellar image. The flare occurred concurrently with the break of the extended group into two well separated spots.
4. On October 26, 1996 another flare was observed in three spectra, as narrow emissions in the He I and Ca II 8498 Å lines but without development in other lines. It was concluded to be a late stage of a flare decay.

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