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On the variable spectrum of HD 45677 (FS Canis Majoris)

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Abstract. We have studied high-resolution optical spectra of the peculiar B[e] star HD 45677 (FS CMa) observed during 3 nights in October 1995. The main results of our analysis can be summarized as follows: (1) The complex and variable profiles of Hβ indicate the presence of matter outflow. Three blue-shifted absorption components have been detected. (2) The inverse P Cygni red-shifted profiles have been observed in the Mg II 4481 Å line indicating the infall of cool gas onto the star. (3) These observations confirm our previous estimate (Israelian et al. 1996) for the projected rotational velocity of the order of 70 km s^{-1}. (4) Accreting gas collides with the atmosphere and/or inner disk material producing the so-called *filling in by emission* effect and/or extended red wings of He I 5876 Å line.

Key words: stars: individual: HD 45677 – stars: Be – stars: peculiar – line: formation – line: profiles

1. Introduction

Spectroscopic properties of HD 45677 have been discussed in detail by Swings (1973) who originally suggested that HD 45677 is a young post-main-sequence object surrounded by a dust shell, left over from formation of the star. Double-peaked Fe II emission lines, on the other hand, indicate the presence of a gaseous disk around the star. A detailed description of HD 45677 has recently been provided by Sitko et al. (1994), Grady et al. (1993), de Winter & van den Ancker (1997) and Israelian et al. (1996, hereafter Paper I) and we presently refrain from it. The lack of obvious nebulosity or a star forming region around this object supports the idea that it is an evolved object (de Winter & van den Ancker 1997). However, the analysis of IUE, IR and polarization data by Grady et al. (1993) suggested that HD 45677 is a massive, HAeBe star with an active accreting circumstellar, proto-planetary disk.

HD 45677 suffers from an ongoing large deep minimum, which started around 1950 with a detected range $V = 7\overset{\mathrm{m}}{.}2 - 8\overset{\mathrm{m}}{.}8$. The minimum has been explained (de Winter & van den Ancker 1997) by an obscuration effect probably due to large ($> 1\mu$m) circumstellar dust grains which were created by an evaporization of a large cometary body or by blown out material around 1950. The detected accretion can be the origin of a bipolar flow (Schulte-Ladbeck et al. 1993, Grady et al. 1993), which could be the region containing small grains.

In his investigation of HD 45677 Swings (1973) found a large number of forbidden and permitted emission lines of Fe II, N II, O I etc. in the optical spectra. The yet unexplained variability in the Balmer, He I and Mg II 4481 Å lines has been discovered by Swings et al. (1980). It is important to mention that all drastic photometric changes between 1960 and 1980 were not accompanied by correspondingly large spectroscopic variations (Sitko et al. 1994). In this paper we briefly discuss some new observations of HD 45677.

2. Observations

Three spectra of HD 45677 were obtained on October 14, 19 and 20 1995 with the Coudé Echelle Spectrometer (Musaev 1993) at the 1-m telescope of the Special Astrophysical Observatory of the Russian Academy of Sciences. The spectra have a S/N ratio > 60 for a resolution element and an average resolution R=36,000 in the wavelength region 4100–6700 Å. Preliminary reduction of the Echelle spectra was made using the DECH code (Galazutdinov 1992) which allows for flat field division, bias/background subtraction, one dimensional spectrum extraction from two-dimensional images, excision of cosmic ray features, spectrum addition, correction for diffuse light, etc.

3. Outflow and infall of the matter

The Balmer lines in the spectrum of HD 45677 have complex profiles consisting of several blue (and sometimes even red) shifted sharp emission and/or absorption components observed over the wide absorption wings of photospheric origin. Let us return to Fig. 1 of Paper I. We observed two narrow absorption components in the Balmer lines. One component was unshifted and most probably produced by absorbing material in an edge-on rotating disk. The second component appeared blue-shifted, as a part of a classical P Cygni profile. The comparison of Hβ,

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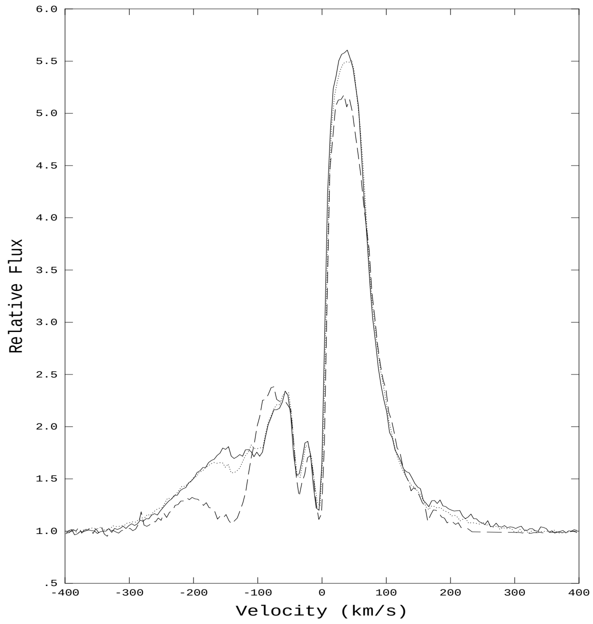

Fig. 1. Observed profiles of Hγ corrected for the system velocity 18 km s^{-1} and presented in the following sequence; 20.10.1995 (full drawn line), 19.10.1995 (dotted) and 14.10.1995 (dashed).

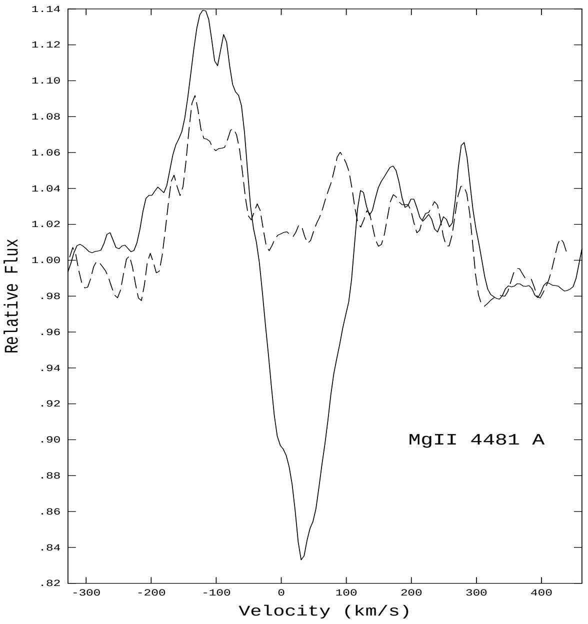

Fig. 2. The variable profiles of Mg II 4481 Å corrected for the system velocity 18 km s^{-1}. The dashed line is the spectrum observed on 14.10.1995 and full line is from 20.10.1995. The profiles were smoothed with a Guassian profile of FWHM=0.2.

Hγ and Hδ lines indicated that the absolute value of the velocity of the blue shifted component $v_{\rm blue}$ is increasing from Hδ to Hβ (i.e. $v_{\rm blue}$(Hβ) > $v_{\rm blue}$(Hγ) > $v_{\rm blue}$(Hδ)). This was understood as an indication that the wind is accelerated. However, there is one detail which currently prevents us from such a severe statement. The problem is that the Hβ line was observed 3 days later than Hγ and Hδ. We know that narrow absorption components observed in the Si II 6347, 6371 Å doublet, the Na I D lines and O I 7771.9 Å may appear and disappear within 2-3 days (Paper I). Thus, there is a possibility that the Hβ profile cannot be considered together with the other 2 Balmer lines because they were not observed simultaneously. Of course there remains a difference between $v_{\rm blue}$(Hγ) and $v_{\rm blue}$(Hδ) of the order of 30 km s^{-1}, supporting the idea of an acceleration in the wind. However, considering the resolution of that data one can still argue against the interpretation of the difference between $v_{\rm blue}$(Hδ) and $v_{\rm blue}$(Hγ) as due to the acceleration of the matter in the wind.

Our recent observations of Hβ show interesting features (Fig. 1). First of all we clearly observe 3 absorption components. The first one at zero velocity has been reported already by us and other observers. It is most probably formed in the edge-on disk. The second variable component is located at about -40 km s^{-1} and has never been mentioned in the literature. We cannot confirm if this component displaces shortward because the resolution of our data is not sufficiently high. The third absorption component appears broad and blue-shifted and is located at -140 km s^{-1}. We clearly record a large variability within 5 days. It appears as if some absorption remains at -140 km s^{-1} and an extra emission showed up in the blue together with a new absorption component at about -100 km s^{-1}. So we do not observe any motion of the component located at -140 km s^{-1}. The picture is quite complex. The total emission in Hβ has increased (as seen also from the emission peak intensity) and in the meantime some absorbing material appeared in the line of sight. In any case, we observe blue-shifted absorption components; a clear indication of the outflow. However, we are not in a position to discuss whether the matter has a positive acceleration in the wind or not. The above described variability of Hβ has been accompanied by a simultaneous variability of the Mg II 4481 Å line. This line may change its shape drastically from a normal absorption into emission profiles with double peaks and/or to P Cygni and/or inverse P Cygni line shapes in a time span of some days. The variability of Mg II 4481 Å profile is presented in Fig. 2. We see how both, the emission and absorption components of the line strengthen within 5 days, giving rise to a clear inverse P Cygni profile.

4. Absorption lines of the neutral helium

Absorption lines of He I form in deep atmospheric layers where accreting matter and a dense atmospheric gas interact. This interaction leads to some primary and secondary effects. Shock waves are expected to form and heat a thin atmospheric layer. The Balmer lines are not affected, because they form in the large and much more extended upper part of the atmosphere and of the envelope. Several lines of He I, Mg II and Ca II are expected to suffer from an anomalous heating.

In the Paper I we described a variability of He I lines and concluded that their cores are filled in by some amount of variable emission. The origin of this emission is still unknown. High-

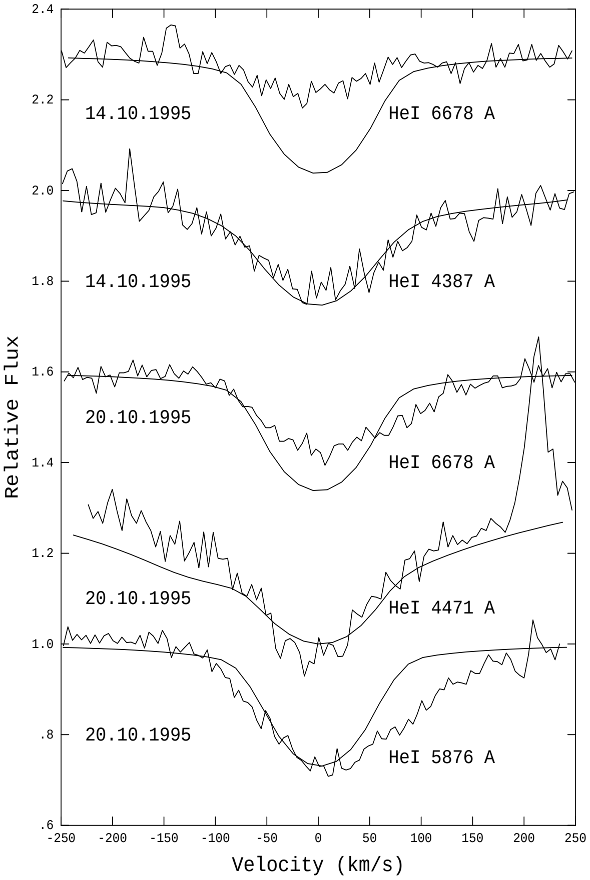

Fig. 3. Theoretical and observed profiles of the He I 6678, 4387, 4471 and 5876 Å lines. The observations of 20.10.1995 (lower panel) and 14.10.95 (upper panel) can be well represented assuming $v \sin i$ = 70 km s^{-1}. The emission at 220 km s^{-1} on the red wing of 4471 Å belongs to Fe II 4474.910 Å. The dates of observations are indicated.

resolution monitoring of the He I 5876 Å line has been carried out in October 1993 (Paper I). The results of this monitoring have been explained by an infall of a cluster of clouds, some of which are accreted. Unfortunately, only a short wavelength range has been covered during this compaign and we were not able to follow other spectral lines. This was partly achieved during the last observations of HD 45677 in October 1995. The variability of the Hβ and Mg II lines, presented in Figs. 1 and 2, was accompanied by a simultaneous variability of all He I lines in our spectra. First of all our new observations confirm our previous estimate (Paper I) of the rotational velocity of $v \sin i$ = 70 km s^{-1}. This result is very important because it will contribute to the solution of the problems which are related to the cause for the filling-in by emission and the problems linked with the determination of the evolutionary status of this star.

Some of the He I lines observed on 20.10.1995 are presented in Fig. 3. For the calculations of the He I lines we adopted $T_{\rm eff}$ = 2.2$\times$10^4 K and $\log g$ = 3.9 (Paper I). The non-LTE profiles were computed with the same program and input parameters as given in Paper I. There is a possibility that a certain amount of the optical veiling permanently exists in the stellar spectra.

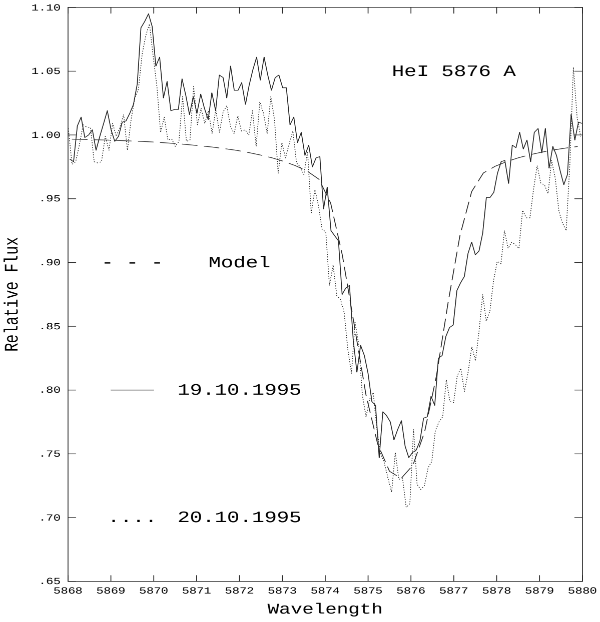

Fig. 4. Fast variability of He I 5876 Å wings. The emission at 5870 Å belongs to Fe II. The dates of observations are indicated.

Apparently the filling-in effect is more pronounced in the 6678 Å line since the latter line has a lower excitation energy. This line was strongly filled in by emission in 14.10.1995 (Fig. 3). It shares the same lower level 2^1P with 4387 Å. The fact that we were able to fit 4387 Å but not the 6678 Å line indicates that the level 3^1D (from which 6678 Å line emerges) is overpopulated relative to its $normal$ non-LTE value. This can be due to the anomalous heating. And finally we were able to fit the He I 4471 Å line. The problem associated with the blue emission wing of He I 4471 Å has been noticed in our previous paper. We are faced with this problem once more (i.e. the observed blue wing becomes much narrower). Clearly, we succeeded in fitting the three helium lines (Fig. 3) because the veiling in these spectra was not as strong as in January 11-14 1995 (see Figs 2 and 3 of Paper I). We again observe day to day variations of these helium lines. Figure 5 shows how the red wing of the line at 5876 Å has developed over a single day. This variation is very similar to the one observed between October 10 and 11 1993. Both events can be characterised by the large variation of the red, and a small (but still noticeable!) variation of the blue wings. It is hard to imagine how the chaotic infall of the cluster of clouds could lead to exactly the same type of the variability after 2 years.

5. Discussion

Because of the co-variations of the emission/absorption components of the Balmer, Mg II and He I lines, one could suggest that they have the same origin. On the other hand, it is clear that the line formation regions of these lines must be different. The red shifted emission peak of Hα has been noticed by de Winter & van den Ancker (1997). Our Fig. 1 shows that the emission peak of Hβ is shifted to the red as well. The Balmer lines do not show double-peaked emission which means they originate in the inner and denser parts of the envelope where the matter is not yet concentrated in the equatorial plane (Swings 1973). The figures 1-3 show that when the blue emission wing of Hβ became stronger, the veiling in helium lines has diminished. The anti-correlation of these two types of emission suggests that we are dealing with an obscuration effect in Hβ. In other words, it is possible that the variation of the Hβ emission wing at -140 km s^{-1} was caused by a passage of a gaseous cloud. The variation of the line-of-sight velocity then produced the extra absorption at -100 km s^{-1}. Now, if one wants to link the variations of all lines with those seen in Hβ, we have to assume immediately that the gaseous cloud (or at least some part of it) has accreted and gave rise to the inverse P Cygni profile of the Mg II line and dumped more neutral helium in the atmosphere (by which the veiling has diminished). Alternatively, we can assume that some other (yet unknown) mechanisms are responsible for the variations of the helium and Mg II lines. Cool gas is clearly observed in the line-of-sight (Fig. 1). The outer envelope is clumpy and the motion of the gaseous clouds gives rise to the sharp absorption components visible in the Na, S and O emission lines. It is possible that we are dealing with some statistical distribution of velocities and position of the gaseous clouds. If so, one can expect that the accretion of these clouds obeys some rules, and the quasi-cyclic variations of the He I 5876 Å line has a obvious explanation. This means that for a given distribution of clouds in the envelope, there will be a non-zero probability to find for example the He I 5876 Å line with a particular shape. These are of course pure speculations and we have no good arguments to assume that the distribution of clouds in the envelope is static (as the matter in the envelope is accreting!). But, if the relaxation time of the ensemble of clouds is much longer compared with the time of the accretion (one-two clouds per day say), then one can assume that such an ensemble is in a quasi-static state. It is too early to make some theory because nobody has tried to subsequently monitor this object during a period of more than 10 days. One needs a good statistical sample before making serious conclusions concerning the nature of the spectral variations seen in these type of objects.

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