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A dense gas-dust cloud near the A-e star DD Serpentis

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Abstract. We present results of the medium resolution spectral observations of a variable A-e star DD Ser. In 1984–1986 the star was found to have a normal double emission Hα-line with equivalent width of emission component EW H$\alpha_e = 13.3 \pm 0.5$ Å. In 1991 a drastic Hα-line profile, as well as photometric variations, were detected. Analysis of the reconstructed profile of the emission line absorption component implies that a dense gas-dust cloud has most likely emerged on the line of sight at the moment of the spectral observations. Quantitative characteristics of the absorption profile variation are given.

Key words: stars: circumstellar matter – stars: emission-line, Be – stars: individual: DD Ser – stars: pre-main sequence

1. Introduction

In the last decade there is growing interest in the early Hα-emission stars which have a narrow hydrogen absorption component (reversal) superimposed on a wider Hα-emission profile. These stars are often found among Herbig Ae/Be star (HAeBes), particularly in that subgroup of variable stars which seem to be nonperiodic Is(A)-type variable stars with unpredictable Algol-like minima (Zajtseva & Kolotilov 1973; Finkenzeller & Mundt 1984; Shevchenko 1989). We shall conventionally call them ALIVARS — Alpha Line (or Algol Like) Irregular VARiable Stars. Spectral observations of the ALIVARS show that the form of the Hα-emission line continually changes, which causes variations of the equivalent widths and ratios of the intensities of violet/red components of the Hα-emission line (Finkenzeller & Mundt 1984; Catala et al. 1986; Chavarria et al. 1988), equivalent widths changing both at low (Zajtseva & Kolotilov 1973) and high (Kolotilov 1977) phases of photometric activity.

To explain the cause of the emission line variations, several diverse physical interpretations have been proposed, such as magnetic fields in photosphere (Herbst et al. 1983; Holtzman et al. 1986; Tjin et al. 1989) and combinations of different physical conditions (Praderie et al. 1986; Catala et al. 1989). Pogodin (1986; 1989) has shown that the diversity of the Hα-emission line profiles can be due to the intrinsic kinematics of an expanding gaseous envelope. At last, a possibility to interpret large-scale changes in the emission line profile by variable extinction in the circumstellar envelope was recently suggested by Grinin & Tambovtseva (1995). Having been caused by continuum level variations the large-scale variations in the emission lines are easily recognized while reasons for rapid small-amplitude ones are still far from complete comprehension.

One of practical difficulties which masks the real behavior of the Hα-emission profile is that the observed Hα-profile includes both an emission component (a tracer of gaseous envelope) and wide absorption photospheric line, the latter being one of the strongest lines in stars of A spectral class.

In this paper we describe an unusual Hα-profile change of DD Ser, paying special attention correct separation of these two components.

DD Ser is not a well studied variable Ae-star, that shows unpredictable light fadings of a few days duration with V-amplitude near 1^m (Meinunger 1965; Tsesevich & Dragomiretskaya 1973). Its MK spectral classification is A5 III and absolute luminosity is M_v = -0$\overset{m}{.}$2 (Timoshenko 1984). The star is not on any known lists of HAeBes since nothing was known so far about its emissivity. To rectify this, the present paper investigates the absorption component (reversal) of the Hα-emission line.

2. Observations and data reductions

UBVR-photoelectric observations of DD Ser were carried out by one of the authors in 1989–90 at Peak Terskol, Caucasus (Kovalchuk, unpublished). Over the course of 42 nights of observations the star was found to slightly vary in the range of 0$\overset{m}{.}$35 (V). No "colour-magnitude" relation could be derived from the observations because of small variation amplitude. However the colorimetric behavior is to get redder while fading, as do other ALIVARS at the normal brightness. Our attention was drawn to the emissive capacity of DD Ser by Dr. A.Tarasov from Crimea Astrophysical Observatory (CrAO), who observed the emission Hα-line earlier (private communication). Spectral observations of DD Ser were carried out at the 6-m BTA of SAO RAS and at the 2.6-m Shain Telescope of CrAO. In the first case we used the spectral complex "Zebra" (Gazhur et al. 1990; Klochkova & Panchuk 1991) mounted at the Nasmyth focus of the BTA.

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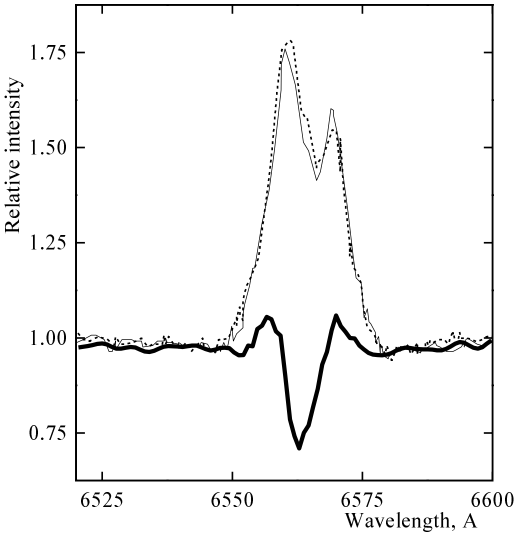

Fig. 1. Variations in the forms of DD Ser emission Hα-profile. Results of the original observations of 1986 (thin line and dots) and 1991 (solid line) are shown.

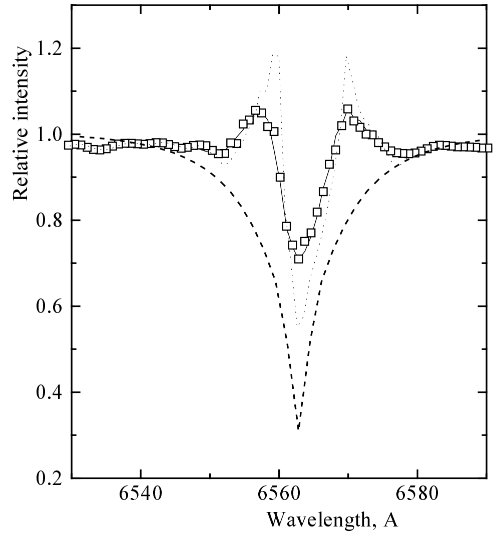

Fig. 2. A comparison of the observed Hα-profile (solid line) with the reference profile P_c (squares). The latter is a result of a convolution of the reconstructed profile R(λ) (dots) with the instrumental profile P_{in}. P_c profile serves to control the reliability of the reconstruction operation only. The dashed line at the bottom of the figure is a theoretical profile of the photosperic Hα-line.

Table 1.

Date	Telescope	Device	Exposition	Z
07.11.86	2.6-m	SPEM	15 minutes	47°
07.15.86	2.6-m	SPEM	15 minutes	48°
02.23.91	6.0-m	ZEBRA	76 minutes	62°

In the second case the grid spectrometer SPEM (Boyarchuk et al. 1967) equipped with a 3-cascade photoelectronic image converter was used. A log of the observations is represented in the following table, with the differences in exposure times explained by specific general sensivity of the detectors.

The first observations of DD Ser with the SPEM showed the bright double emission Hα-line. On the SPEM spectra (07.11 and 07.15) the profiles of Hα-line are completely consistent and similar to lines observed in other A-e stars with Algol-like minima (Kolotilov 1977; Finkenzeller & Mundt 1984; Pugach & Kovalchuk 1993). The main body of the emission lines is divided by a strong absorption component (reversal) of moderate intensity (Fig. 1), thin and dotted lines).

However, the third spectrum, as distinct from the two previous ones, shows an anomalously strong absorption component and a very weak emission one. The intensity of the reversal is one of the strongest so far observed in this and other Is(A)-type stars. Its central intensity is fairly far below the continuous spectrum (Fig. 1, solid line).

An objective of the present work is to obtain the refined profile of the emission Hα-line, free of any distorting influence of the apparatus function and the underlying wide absorption hydrogen line. The full image treatment procedure and several details of the spectrogram processing are described elsewhere (Galazutdinov 1992; Kovalchuk & Pugach 1997). The instrumental profile $P_{in}(\lambda)$ (FWHM = 1.93 Å) was carefully determined using 9 single well separated lines of a thorium-argon spectrum (D'Odorico et al. 1984) in the vicinity of the Hα-line. These data were used when applying the deconvolving procedure of the observed profile. While performing the reconstruction procedure of the hydrogen line it was supposed that the only distorting factor responsible for the line broadening is the instrumental line response function. All other effects are considered to be negligible.

To obtain an undistorted contour of the absorption component, the numerical method described in Gurtovenko (1966) and de Jager (1966) for the solar spectrum lines was used. A run of three subsequent iterations seemed to be sufficient for the reducing process to be completed and a reconstructed profile R(λ) obtained (see dotted line in Fig. 2). To check whether this reconstructed profile R(λ) is correct we used the following approach. Profile $R(\lambda)$ was convoluted with $P_{in}(\lambda)$ and the control profile P_c

$$P_c(\zeta) = \int R(\zeta - \Delta\lambda) \times P_{in}(\Delta\lambda) \times d\lambda$$

thus obtained was then compared with the observed profile P_o. The result of the comparison P_c (squares) and P_o (solid line) is shown in Fig. 2, which shows that P_c matches P_o very well, with the difference between P_c and P_o being less than 0.02 of the continuum intensity. However, the profile R(λ) is not yet a true one since it is influenced by the wide hydrogen absorption line just below. Hence, the latter should be taken into consideration but then eliminated. For the true profile T(λ) to be obtained the subtraction

$$T(\lambda) = R(\lambda) - H\alpha_{ab}$$

was performed where $H\alpha_{ab}$ is a theoretical profile of the absorption H_α-line for T_{eff}= 8600 K and lg g=2.4 is calculated us-

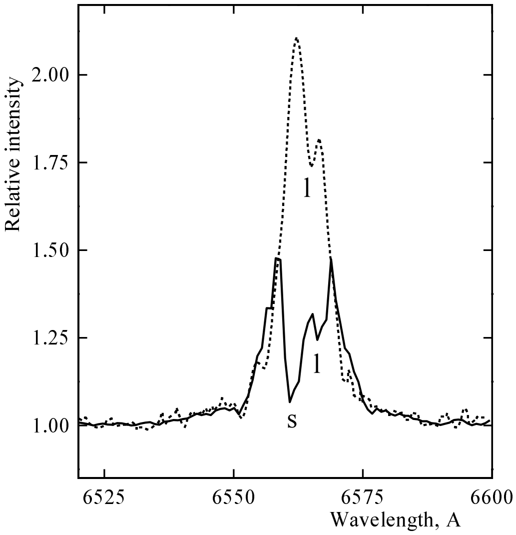

Fig. 3. Comparison of the true profiles of DD Ser emission Hα-line obtained at different dates. The solid line is the reconstructed profile of 1991 observations. The dashed line is the same for 1986 observations previously averaged. In both cases the Hα photospheric absorption profile was properly accounted. The difference between the areas occupied with the profiles corresponds to the equivalent width W_a.

ing Kurucz's method (Kurucz 1979). The effective temperature T_{eff} and the gravity parameter lg g were previously drawn out from the spectral observations of the star (Kovalchuk & Pugach 1997). The profile T(λ) shown in Fig. 3 (solid line) represents the true Hα-profile of the emitting envelope.

3. Discussion of the results

While analyzing the spectra, we supposed that the 1991 spectrum reflected an unusual stage of the star; otherwise 1986 data have been recorded at the normal star condition. We try to estimate the brightness of the star in order to assess whether enhanced circumstellar extinction may be supposed to be a reason of both brightness and drastic spectral variations. Unfortunately no proper photometric data were available at this time. The nearest photometric observations of DD Ser are by Kovalchuk (unpublished) but lasting only up to 10.10.1990. However several other ALIVARS (V351 Ori, IP Per, BO Cep and RR Tau) have been registered on BTA at that night under the same conditions. To evaluate the photometric value of DD Ser we compared responses obtained for all five stars at the fixed wavelength λ=4350 Å. This wavelength corresponds to the B-band isophotic wavelength of the standard photometric system UBVR. To do so it was supposed that the four reference stars with known B-values were at the moment of spectral observations at the normal photometric state V_n excluding deep algol-like minima. In any case one of the stars, namely V 351 Ori, was at normal brightness, confirmed by the HIPPARCOS data in a time interval covering the period of the DD Ser spectral observations. Three other "reference" stars are not thought to be at deep minimum since their equivalent widths of Hα-emission lines correspond to the normal rather than weakened light level. The Hα-profile of these stars seemed to be absolutely normal (Kovalchuk & Pugach 1997) suggesting no deep light minima. After the following necessary parameters have been taken into consideration,

- magnitude of the normal brightness V_n;
- observed colour-indexes B-V (Pugach & Kovalchuk 1991; Pugach 1996);
- exposition time;
- zenith distance Z;
- averaged coefficient of atmospheric extinction and
- specific apparatus constant

four independent B-magnitudes of DD Ser were drawn. The range is $12^{\rm m}.12 \leq B \leq 12^{\rm m}.60$, with the mean $\bar{B}$=$12^{\rm m}.34 \pm 0^{\rm m}.11$.

The value $\bar{B}$ thus obtained may be compared with results of the photographic brightness investigations of DD Ser by Tsesevich & Dragomiretskaya (1973). The comparison is justified since the isophotic wavelength of the B-band and m_{pg}-band for A spectral class are appropriately closed ($\Delta\lambda \approx$170 Å). Accordingly Tsesevich and Dragomiretskaya, the normal m_{pg}-magnitude of DD Ser equals $10^{\rm m}.7$ while at minimum light it drops to $12^{\rm m}.5$. Thus within the reservations mentioned it is safe to say that DD Ser at 02.23.91 was in a state near minimum light. The finding of the exact DD Ser B-magnitude was not an objective of the above calculation. An important point is that at the moment of the spectral observations the photospheric radiation of DD Ser was highly suppressed. In such an event the obscuration may be supposed to bear on the spectral changes.

We have additional proof that the 1991 spectrum is unusual, while the rest of DD Ser were obtained at the normal state. Dr. Tarasov A.E. from the CrAO observed DD Ser in 1984–1985 at the same telescope and with the same equipment and put three spectra of DD Ser at our disposal to compare profiles and equivalent widths. In all 1984–1985 spectrograms (Fig. 4) the Hα-line of DD Ser looks just the same as it does in our two 1986 spectra (Fig. 1). Thus five spectra out of six comprise the normal state of the star in 1984–1986, and give equivalent widths of Hα-emission component close to the value of W_e = 13.3±0.5 Å, which is appropriate for Is(A)-type star at normal state. But the spectrum obtained in 1991 at the 6-m telescope shows the distinguished profile and decreased equivalent width of a Hα-emission component. Thus the 1991 observation reflects noticeable spectral and photometric variations of the star. The 1991 Hα-profile and photometric variations were caused by emergence of a dust-gas cloud on a line of sight, it is possible to evaluate optical depths τ in cloud both in the Hα-line itself τ_α and at the neighboring continuum τ_c. The τ_c value can be drawn from the value of light extinction at λ=4350 Å which is equal to

$$\Delta{\rm m}(4350) = 12^{\rm m}.34 - 10^{\rm m}.70 = 1^{\rm m}.64.$$

Then

$$\tau_c(4350) = 0.917\Delta{\rm m}(4350) = 1.50.$$

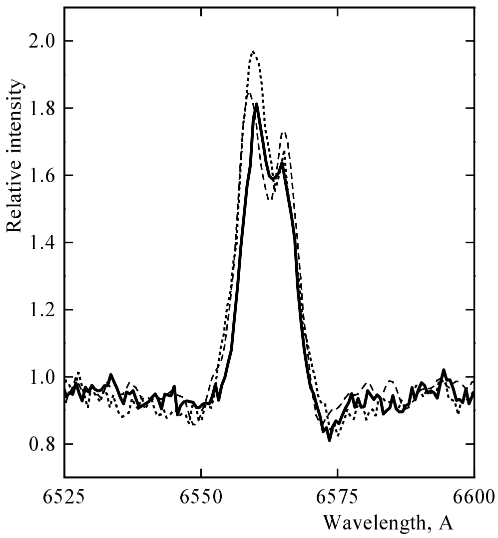

Fig. 4. Three 1984–1985 spectrograms of DD Ser at normal brightness show no noticeable spectral variations as compared with 1986 observations. The dates of observations are: dots – 05.22.84; dashed line – 12.01.84; solid line – 05.22.85.

The necessary value of $\tau_c(6563)$ at the λ=6563 Å was estimated using the wavelength dependence of the extinction coefficient $\chi_\lambda \propto \lambda^{-1.4}$ found for other ALIVARS (Kovalchuk & Pugach 1991). Then

$$\tau_c(6563) = 0.663\tau_c(4350) = 0.993.$$

The true profile T(λ) with equivalent width W_t = 6.96 Å, allows us to determine equivalent width and central intensity of the reversal. If the 1984–1986 observations comprise a stage of the normal spectral state, then the difference between any reconstructed 1986 profile and the profile T(λ) would give the equivalent width W_a of the reversal. The mean reconstructed profile of the season 1986 is shown on Fig. 3 by a dashed line. This profile was treated in the same way and then subtraction of $H\alpha_{ab}$ was performed. However the accuracy of this reconstructing procedure is lower because the instrumental profile of SPEM spectrometer is of poorer quality. The value of the W_a thus obtained seems to be near W_a = W_e - W_t = 6.34 Å. This value proves that a great obscuration occured on 02.23.91 as compared with 1984–1986 observations. We interpret this drastic Hα-profile variation as due to emergence of a dense complex gas-dust cloud on the line of sight. The low limit of the optical depth of the hypothetical cloud in Hα-line is $\tau_{\alpha min} \geq 2.21$ as estimated from the central intensity of the reversal. Although exact optical depth is unknown, the value $\tau_{\alpha min}$ implies that a great mass of the circumstellar substance has obscured a significant part of the radiation from the emission envelope and the photosphere.

The ratio W_a/W_e=0.48 (where W_e=13.3 Å is averaged equivalent width of the emission line at the "normal" state) points out that the angle sizes of emission envelope Ω_e and hydrogen cloud Ω_c is of one order. Otherwise, if $\Omega_e \gg \Omega_c$ any great value of τ_{min} would not explain the observed ratio of W_a/W_e. Thus, if the cloud occupies a small part of a sphere 2π radians, then the emission envelope does the same and it should be disk-like or flattened.

The form of the T(λ) profile in Fig. 3 interesting because of the two absorption components l (longwave) and s (shortwave). Although the l-component may be questioned, the presence of the more prominent s-component is obvious. Its shortward displacement by 2.35 Å relative to the centroid of the Hα-emission line shows the gas velocity near 107 kms^{-1} out from of the star. This s-component may be related to the newly formed short-lived obscuring cloud, occasionally projected on the line of sight. If so, we may suppose that matter eruptions occur near the star from time to time.

DD Ser belongs to the group of variable stars which occupy the loci of the giants and of the more luminous stars on the "T_{eff} - lg g" diagram (Kovalchuk & Pugach 1997). Several stars of the group (for example, V351 Ori [Kovalchuk & Pugach 1998]) have narrow absorption lines Hβ, Hγ, Hδ, which can be interpreted as the result of relative hydrogen deficiency in their atmospheres. The presence of the deep, shortwave shifted hydrogen absorption s-component in the spectrum of DD Ser shows accidental eruption processes, which may cause hydrogen-rich layers to be removed off from the stellar photosphere. Sooner or later such an eruption process may lower the hydrogen abundance in the star and be a reason for the weak hydrogen lines observed.

How equivalent width W_e of Hα-line depends on the star's brightness is not evident. There is probably not a one-to-one correspondence between photometric B-magnitude and W_e. An effort to calculate the relation (B vs W_e) is complicated by the fact that the physical characteristics of the star and the stellar environment are almost unstudied. Moreover the interrelative positions of the obscuring cloud and the emission envelope, being absolutely unknown, seem to be a governing factor. At one and the same physical conditions of the envelope and cloud the observed equivalent widths W_e may be subjected to wide variations depending on what object is nearest to the observer.

Most commonly the obscuring cloud appears between the emission envelope and the photosphere of ALIVARS. In that case, as the star's brightness decreases, W_e increases (see, for example, Kolotilov 1977). Otherwise, when the source of continuum opacity is above the emission envelope, then the changes of the fluxes from the emission envelope and the photosphere are almost proportional. Therefore no significant variations would be observed in W_e. If the obscuring cloud contains some neutral hydrogen, it would result in Hα-line flux and consequently decreasing W_e.

At the moment it is not clear enough which model of the phenomenon is preferable. However two points may be thought are certain. First, at least some part of the obscuring cloud is situated over the emission envelope, and second, the cloud encloses some amount of neutral hydrogen.

As no relevant data on $v \sin i$ of DD Ser are available, we failed to take the rotational effect into account. However it seems to be negligible since expected rotation has no practical influence on the form of the broad hydrogen absorption lines of A type stars.

4. Conclusion

An unusual strong variation of the Hα-emission line profile has been detected at the moment of deep light fading of the star. A strong absorption component superimposed on the Hα-emission shows the presence of a opaque hydrogen cloud on the line of sight. The short-wave shifted component may support the identification of a occasional dense hydrogen cloud or a jet retiring the stellar environs. If so, the velocity of the escaping cloud may well be near 110 kms^{-1}. The event registered evidences an accidental eruption process in the upper atmosphere of DD Ser.

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