Mon. Not. R. Astron. Soc. **298,** 275–284 (1998)

Spatially resolved optical spectroscopy of the Herbig Ae/Vega-like binary star HD 35187

S. K. Dunkin and I. A. Crawford

Department of Physics and Astronomy, University College London, Gower Street, London WC1E 6BT

Accepted 1998 March 6. Received 1998 January 27; in original form 1997 September 19

ABSTRACT

We report on observations of the young binary system HD 35187 (SAO 77144). For the first time, we have obtained spatially resolved optical spectra of the individual stars. Analysis of their effective temperatures indicates that the stars have spectral types of A2 (HD 35187B) and A7 (HD 35187A). Analysis of the Hγ Balmer line indicates a luminosity class V for both stars. At the time of these observations, net Hα emission was present only towards HD 35187B. However, there is evidence that the photospheric Hα line in HD 35187A has been 'filled in' relative to its expected strength in an A7 star, so this star may also be associated with some process leading to Hα emission. Moreover, *both* stars exhibit absorption in the He I λ5876 line well in excess of that expected for their spectral types. Comparison with earlier observations reveals that both the Hα and He I lines are variable, so both stars are 'active' in some sense. We suggest that the variable He I absorption detected towards both stars is a result of chromospheric activity, and is not necessarily related to the circumstellar environment.

We find tentative evidence for a narrow Ca K circumstellar absorption line and excess redshifted absorption of the Na D line profiles in the spectrum of HD 35187B, both of which are absent in the spectrum of HD 35187A. The heliocentric radial velocity of the presumed circumstellar Ca K line ($+54.5$ km s^{-1}) is similar to that of redshifted circumstellar absorption lines previously identified in *IUE* spectra of this star, and the velocity range of the Na D absorption precisely matches that of the UV circumstellar components. Moreover, by placing the stars on the HR diagram (with the aid of the reliable *Hipparcos* distances) we find evidence that HD 35187B is dimmed by about 0.4 mag of grey circumstellar extinction.

The detection of net Hα emission, circumstellar absorption lines, and significant circumstellar extinction for HD 35187B suggests that it has far more mass in its circumstellar environment than its companion, and that the observed IR excess of this system originates from a disc surrounding HD 35187B alone.

Key words: binaries: spectroscopic – stars: individual: HD 35187 – stars: pre-main-sequence.

1 INTRODUCTION

Herbig (1960) originally suggested a list of 26 stars which are considered to be the higher mass counterparts to the young T Tauri stars. These Herbig Ae/Be (HAeBe) stars are pre-main-sequence, intermediate-mass stars generally with an infrared (IR) excess emission attributable to the presence of dust in the circumstellar environment. The original criteria for membership of this class, as laid down by Herbig, were revised by Bastien et al. (1983), who suggested that HAeBe stars should be considered as 'stellar objects, earlier than F0, associated with a region of obscuration and a reflection nebula; in their spectrum they exhibit emission lines of the Balmer series of hydrogen'. Herbig's list was expanded by Finkenzellar & Mundt (1984), who studied the emission lines of 57 HAeBe stars. Since then, the list of members or possible members of the class has risen significantly, with Thé, Winter & Pèrez (1994) cataloguing over a hundred such objects.

Here we report new observations of the possible HAeBe star system HD 35187, which lies at a distance of 150 ± 55 pc (ESA 1997) in the Taurus molecular clouds. Attention was first drawn to this object when it was discovered to have an IR excess similar to the 'Vega-like' stars found by the *IRAS* survey (Walker & Wolstencroft 1988; Oudmaijer et al. 1992). Dunkin, Barlow & Ryan (1997a,b) included HD 35187 in their optical study of 14 Vega-like stars, but noted that the star has very similar characteristics in its optical spectrum to Herbig Ae stars. It has also been classed as a HAeBe star by Böhm & Catala (1994, 1995) and by Grady et al. (1996). The observations of Dunkin et al. (1997b) revealed changes in the Hα emission-line profile when compared with observations by other authors, and such spectral variability is not uncommon in HAeBe systems.

Although much of the recent work on HD 35187 has tended to assume it to be a single star, it has been known to be a close multiple system since the middle of the last century. The Washington Visual Double Star Catalogue (Worley & Douglass 1996) lists three stars in the system: two components of similar brightness ($V \approx 8.5$), separated by 1.3 arcsec, and a much fainter ($V \approx 15.5$) component lying 8.7 arcsec from the brighter pair. The two brighter stars of the system have now been observed by the *Hipparcos* mission (ESA 1997). The *Hipparcos* Catalogue Double and Multiple Systems Annex (DMSA) lists component 'A' as having a *Hipparcos* magnitude $H_p = 8.734 \pm 0.017$, and component 'B' (the more northerly component) as having $H_p = 8.586 \pm 0.015$ (note that the *Hipparcos* magnitude, H_p, is very similar to the Johnson V magnitude; cf. p. 59 of Vol. 1 of ESA 1997). Thus, rather unusually, the *Hipparcos* catalogue has assigned the identifier 'B' to the brighter component of the pair. In order to avoid confusion, we will follow the *Hipparcos* nomenclature. The angular separation of the principal components is 1.386 ± 0.005 arcsec, with a position angle of 192° (DMSA).

The main aim of the present work was to obtain separate spectra of these components in order to determine whether both are Herbig Ae stars, and to identify other differences between them which may affect the interpretation of the circumstellar environment. In addition, we were interested in searching for circumstellar absorption lines similar to those found towards the Vega-like star β Pictoris.

2 OBSERVATIONS AND DATA REDUCTION

The observations were performed on 1996 November 27 with the 3.9-m Anglo-Australian Telescope (AAT), using the UCL echelle spectrograph (UCLES) with the 79 line mm^{-1} grating. The detector was the AAO Tektronix CCD (1024×1024 24-μm pixels, binned by a factor of 2 in the spatial direction). Two separate exposures were made, with central wavelengths of 4010 Å (giving incomplete spectral coverage from 3660 to 4515 Å), and 6216 Å (covering the range 5060 to 8330 Å). The individual orders were extracted from the CCD image using the FIGARO data-reduction package (Shortridge 1988), and background light was measured from the interorder region and subtracted. Wavelength calibration was performed using the standard Th-Ar comparison lamp. The slit width was set to 1 arcsec, and the seeing was measured to be in the range 1.5 to 2.0 arcsec. The spectral resolving power, measured from the FWHM of the comparison lines, was $R = 45\,000$ (6.6 km s^{-1} FWHM).

In order to record spectra of the two components, the slit was aligned along a position angle of 20°, which appeared to be the axis of the system as seen by the slit-viewing camera at the telescope. This angle is somewhat uncertain, because the two stars were not resolved in the image reflected from the slit jaws, and is rather different from the 12° (i.e., $192° - 180°$) subsequently given in the *Hipparcos* DMSA. However, given the slit width, the angular separation of the components, and the prevailing seeing, we are confident that most of the light from both stars entered the spectrograph.

The 1.39-arcsec separation of the two stars projects to 115 μm at the detector in the spatial direction, or 2.4 of the binned Tektronix CCD pixels (Ryan & Fish 1995, pp. 7–8). Fig. 1 shows the region of echelle order 34, which contains the Hα line (6562.8 Å). It is clear from this image that bright emission in Hα is visible in only one of the two stars (the northernmost of the pair, HD 35187B), and is in absorption in the other. This clearly shows that we have been able to obtain spatially resolved spectral information, even though the seeing discs of the two stars are not fully resolved. Fig. 2 illustrates this by showing the effect of blending the seeing discs (1.5 arcsec FWHM) of two stars separated by 1.29 arcsec, binned down to the 0.58 arcsec pixel^{-1} image scale. It seems clear from Fig. 2 that, by rejecting the central four rows (2.3 arcsec) of each order, it should be possible to obtain a spectrum of each star separately from the wings of the seeing profile. Careful extraction of the individual detector rows confirms that contamination of the spectrum

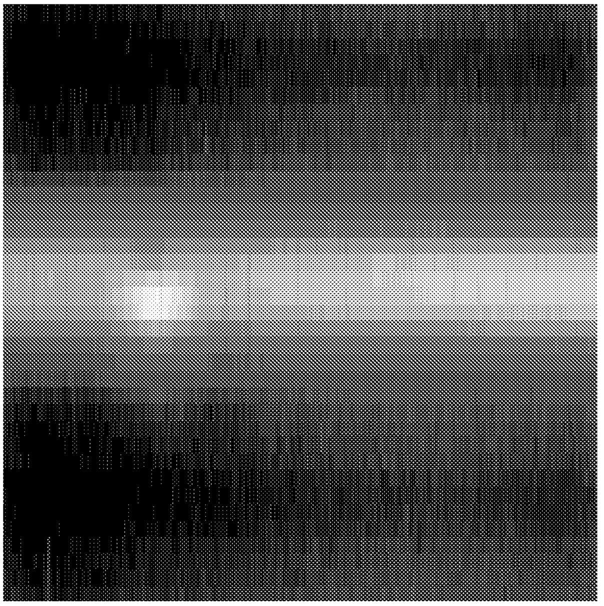

Figure 1. CCD image of the region of the Hα line, showing clearly that Hα is in emission in one of the two stars and in absorption in the other. Wavelength increases from left to right (from 6544 to 6616 Å), and north is towards the bottom.

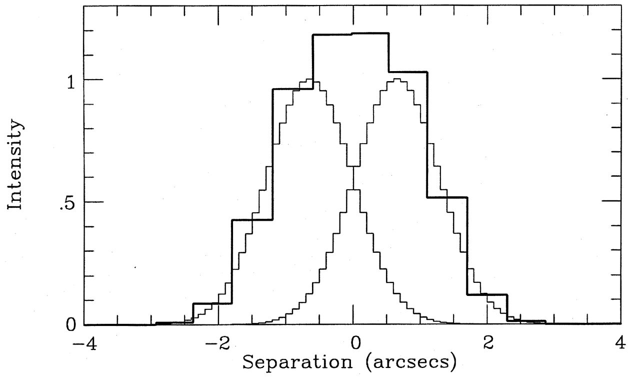

Figure 2. The effect of blending the seeing profiles (each 1.5 arcsec FWHM) of two stars separated by 1.39 arcsec, and binned down to the spatial pixel scale (0.58 arcsec pixel^{-1}) of the present observations.

of one star by the other has indeed fallen to a very low level (we estimate $\lesssim$5 per cent) for angular distance $\gtrsim \pm 1.2$ arcsec from the centre of each order.

3 BASIC STELLAR PARAMETERS

3.1 Spectral type

HD 35187 is classified as A2:V: in the latest version of the General Catalogue of MK Spectral Types (Buscombe 1995, where the colons mean that both the spectral subclass and the luminosity class are uncertain). To the best of our knowledge, the spectral types of the two components have not yet been determined individually, and an initial inspection of spectra revealed significant differences between them.

In order to quantify these differences, the spectrum synthesis code UCLSYN (Smith 1992) was used to compute local thermodynamic equilibrium (LTE) solar-metallicity model atmospheres (utilizing the code ATLAS6; Kurucz 1979). Initially, models were generated assuming $T_{\rm eff} = 8990$ K (Gray & Corbally 1994), $\log g = 4.1$ cm s^{-1} (Allen 1973), a microturbulent velocity $\xi = 3.0$ km s^{-1}, and a rotational velocity $v \sin i = 93$ km s^{-1} (Dunkin et al. 1997a). Adjustments of these values to match the observed data resulted in effective temperatures of 8990 ± 400 K (A2) for HD 35187B and 7800 ± 400 K (A7) for HD 35187A. These temperatures were obtained by modelling over 30 lines from the Kurucz (1995) line list. As an example, Fig. 3 shows an expanded view of the 4500-Å region for both stars, with synthetic spectra appropriate for a range of temperatures superimposed. It will be seen that our quoted range of ± 400 K brackets the data fairly well, and that it is quite impossible to fit both stars with the same temperature.

The luminosity diagnostic hydrogen lines were not properly covered in our UCLES wavelength settings. However, additional low-resolution spectra of the two stars were kindly obtained for us by Dr Mike Bessell, using the Australian National University 2.3-m telescope at Siding Spring, on 1997 March 1. We have modelled the Hγ line in these spectra, and have obtained an estimate of the surface gravities of the two stars (Fig. 4).

The stellar parameters that we have derived for this system are summarized in Table 1. The $v \sin i$ of both stars

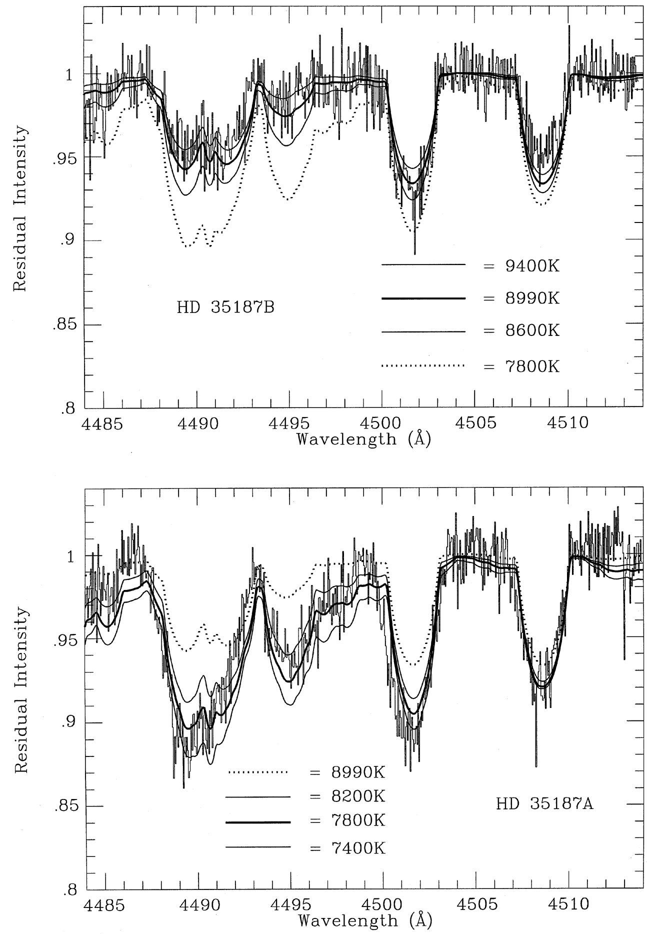

Figure 3. The observed 4500-Å region for the two stars. The smooth lines represent synthetic spectra calculated for different effective temperatures using the UCLSYN program (Smith 1992). It is apparent that a temperature range of ± 400 K brackets the observed data quite well. In addition, for each star we show the model appropriate for the best-fitting temperature of the other, and it is clear that both stars cannot be fitted with the same effective temperature.

appear to be very similar, with little deviation from the 93 ± 5 km s^{-1} value previously found for the system (Dunkin et al. 1997a). Although the measured heliocentric velocities of the two stars appear to be different by 3 km s^{-1}, we do not consider this to be statistically significant.

3.2 Evolutionary status

For a HAeBe classification to be strictly correct, HD 35187 must be a pre-main-sequence object, not yet having reached the zero-age main sequence (ZAMS). To determine their evolutionary status, we have placed both components of the system on an HR diagram, using the accurate distances, and other observational data, given in the *Hipparcos* catalogue (ESA 1997). For the purpose of estimating the visual extinction, we obtained the $(B-V)$ colour index from the Tycho magnitudes (B_T, V_T), using the formula given in ESA (1997, Vol. 1, p. 60), and intrinsic colours from Schmidt-Kaler (1982). This resulted in a visual extinction $A_V[\equiv 3.1E(B-V)]$ of 0.43 mag. The absolute magnitudes

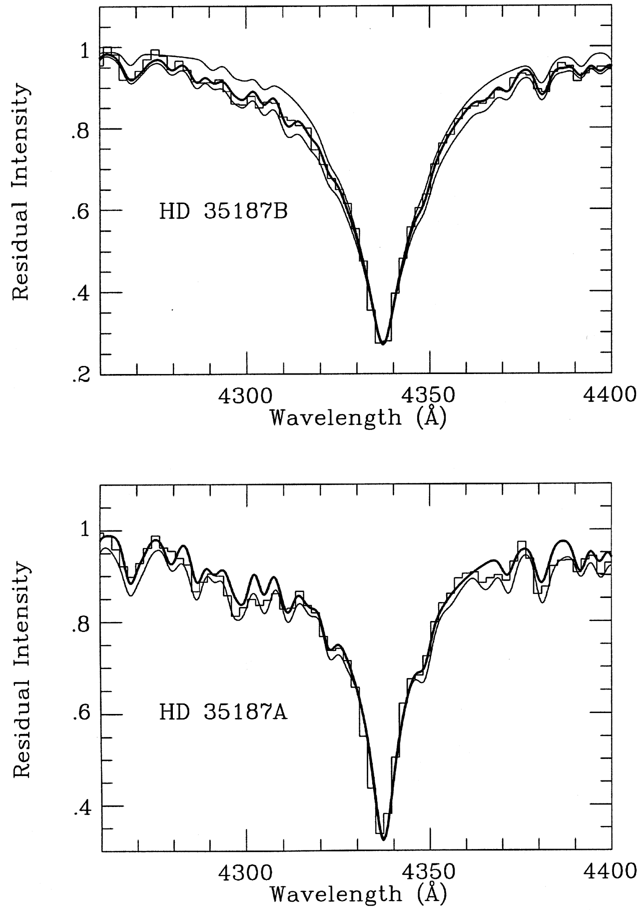

Figure 4. The observed Hγ line profiles (M. S. Bessell, personal communication) compared with theoretical profiles for a range of surface gravities. For HD 35187B, the thick line indicates $\log g = 4.2$, with models for $\log g = 4.1$ (upper) and 4.5 (lower) also shown. The thick line (best-fitting model) overlying the HD 35187A spectrum represents $\log g = 4.1$, and the weaker line is for $\log g = 4.2$; it was found that a $\log g = 3.9$ value was barely distinguishable from the $\log g = 4.1$ model.

Table 1. Derived stellar parameters for the HD 35187 binary system. T_{eff} is the effective temperature; ξ is the microturbulent velocity; $v \sin i$ is the projected rotational velocity; and $V_{\odot}$ is the heliocentric radial velocity.

Star	T_{eff} (K)	Sp. Type	log$g$ (cm s^{-2})	ξ (km s^{-1})	$v$sin$i$ (km s^{-1})	$v_{\odot}$ (km s^{-1})
A	7800 ± 400	A7	4.1±0.2	3.4 ± 0.3	90±10	28±4
B	8990 ± 400	A2	4.2±0.1	3.0 ± 0.3	95±10	31±3

were then calculated using the standard distance-modulus relation, adopting the *Hipparcos* distance (150 ± 55 pc) and V magnitudes converted from the *Hipparcos* (H_p) magnitudes using the relations given in Vol. 1 of ESA (1997, p. 59). Bolometric magnitudes were derived using the bolometric corrections given by Schmidt-Kaler, which were then used to obtain values for $\log(L_*/L_{\odot})$ for both stars.

Fig. 5 shows the positions of the two stars on an HR diagram. The errors indicated on the luminosities reflect the 1σ errors on the distance quoted in the *Hipparcos* catalogue.

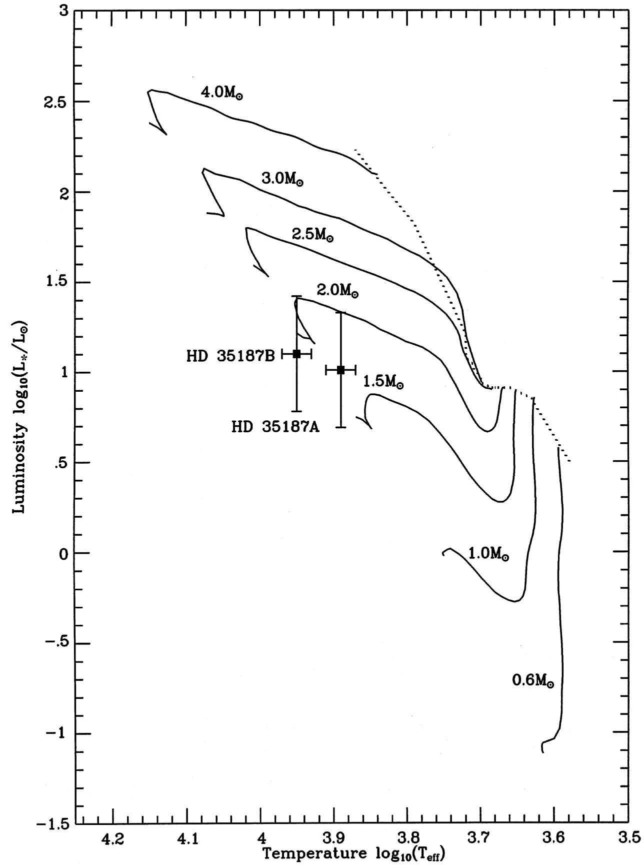

Figure 5. Evolutionary tracks in the HR diagram, taken from Palla & Stahler (1993). The birthline (dotted line) lies to the right of the diagram, the ZAMS to the left. The two stars in the HD 35187 system are marked, showing that they lie close to or on the main sequence. The vertical error bars correspond to the 1σ errors on the distance given in the *Hipparcos* catalogue.

However, as the stars form a binary system, and are therefore at the same distance, they must retain a constant (0.1 dex) difference in luminosity, irrespective of how they are allowed to move vertically in the diagram as a result of the distance uncertainty. The evolutionary tracks in Fig. 5 are taken from Palla & Stahler (1993), and start at the birthline (i.e., the point at which protostar accretion stops), and end at the ZAMS.

From Fig. 5, it appears that both stars in the HD 35187 system lie on, or close to, the ZAMS. However, given their respective effective temperatures (Table 1), we would expect HD 35187B to be more luminous than its cooler companion by about 0.4 dex (cf. Schmidt-Kaler 1982). Indeed, the simple observation that two stars with effective temperatures differing by 1200 K have such similar luminosities immediately tells us that there is something peculiar about the HD 35187 system: most probably that the two stars are affected by differing amounts of circumstellar extinction.

From Fig. 5, we see that HD 35187A is located close to the 1.7-M$_{\odot}$ evolutionary track at an age of 10 Myr (cf. the time markers given in fig. 10 of Palla & Stahler 1993). Given that the stars form a binary system, and therefore presumably formed together, we can use the evolutionary tracks to determine the mass and luminosity of HD 35187B for the same age of 10 Myr. We find that a self-consistent solution is possible if the intrinsic luminosity of HD 35187B is actually 45 per cent (0.16 dex, or 0.4 mag) higher than indicated in Fig. 5, in which case the star would have a mass of about 2.1 $M_\odot$ and would lie just above the ZAMS. Of course, this would imply that HD 35187B suffers from an additional 0.4 mag of (mostly grey) circumstellar extinction caused by relatively large (radii >0.1 μm) grains in its circumstellar environment. This explanation is consistent with the work discussed in Sections 4 and 5 below, which suggest that HD 35187B is surrounded by a substantial disc of gas and dust, while HD 35187A is not.

It is interesting to note that the position of the stars on the HR diagram strongly supports a distance close to the middle of the 150 ± 50 pc range given in the *Hipparcos* catalogue. If they were close to the (1σ) lower limit of 100 pc, both stars would lie significantly below the main sequence; on the other hand, if they were as distant as the 200-pc upper limit, not only would they then be well beyond the estimated distance of the Taurus clouds (140 pc, Ungerechts & Thaddeus 1987), but they would lie on the same evolutionary track (2.0 $M_\odot$) at different ages, which is inconsistent with them forming together as a binary system.

4 INDIVIDUAL LINES OF INTEREST

4.1 Hα

Hα emission from the HD 35187 system has been observed on several previous occasions (Zuckerman 1994; Böhm & Catala 1995; Grady et al. 1996; Dunkin et al. 1997b). It is clear from these earlier observations that the Hα emission-line profile is highly variable. The line generally has a double-peaked profile (similar to a Beals [1950] Type III Cygni profile), but with considerable variations in the depth of the central reversal. For example, compare fig. 3 of Zuckerman (1994), where the central absorption extends below the adjacent continuum, with fig. 3(a)i of Dunkin et al. (1997b), where it is very much weaker. Moreover, in the former spectrum, the central reversal is displayed towards the red, whereas for a true Type III P Cygni profile it should be displaced towards the violet. This redshifted absorption would seem to suggest the presence of infalling material. This is also true from the spectrum presented by Grady et al. (1996, their fig. 14) which, although classed by them as Beals Type III, actually appears to be very similar to a classic inverse P Cygni profile. On the other hand, our integrated Hα profile (i.e., summed over both stars) shows only a single-peaked emission, superimposed on an underlying broad stellar absorption line (i.e., Beals Type VI), and Böhm & Catala (1995) also observed only a single-peaked emission profile. Thus at least one of the components of the HD 35187 binary system exhibits variable Hα emission.

In Fig. 6 we present the Hα line profiles for the two stars separately. As already noted, it is clear that the observed Hα emission is contributed by HD 35187B (cf. also Fig. 1). However, close inspection of the wings of the HD 35187A profile suggests that this star may also have an Hα emission component superimposed on the photospheric absorption line. To explore this possibility, the observed profiles were divided by the photospheric profiles (generated using UCLSYN) expected for an A2 star (HD 35187B) and an A7 star (HD 35187A). Fig. 7 shows the result, and it is apparent that HD 35187A also seems to exhibit a single-peaked residual Hα emission profile.

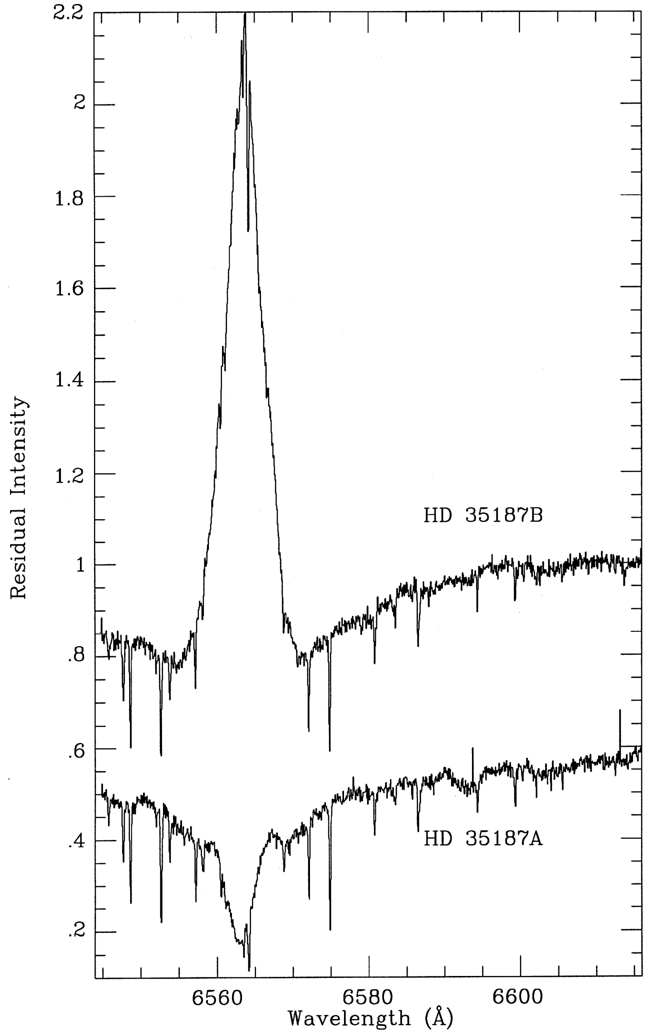

Figure 6. The Hα profiles of the two stars as extracted from the raw data. The numerous very narrow lines, including those in the core of the Hα lines, are due to atmospheric water vapour. HD 35187A had been offset by -0.4 in residual intensity for clarity.

To check that the apparent emission in HD 35187A is not caused by stray light from HD 35187B, each of the rows used to produce the final spectrum of HD 35187A was analysed separately. All of the rows were found to exhibit the additional wing emission to some degree. As an additional check, we constructed an artificial spectrum by combining an extracted row of the net emission-line star and a photospheric model of an A7 star with no Hα emission. These were separated by the appropriate distance (1.39 arcsec) and convolved with a Gaussian (2.0 arcsec FWHM) to reproduce the effect of the (worst case) seeing on the night of observation. No appropriately extracted row from the reconstructed spectrum was able to reproduce the emission seen in a corresponding row of the real spectrum of HD 35187A. We therefore conclude that there has not been significant contamination of the HD 35187A spectrum by

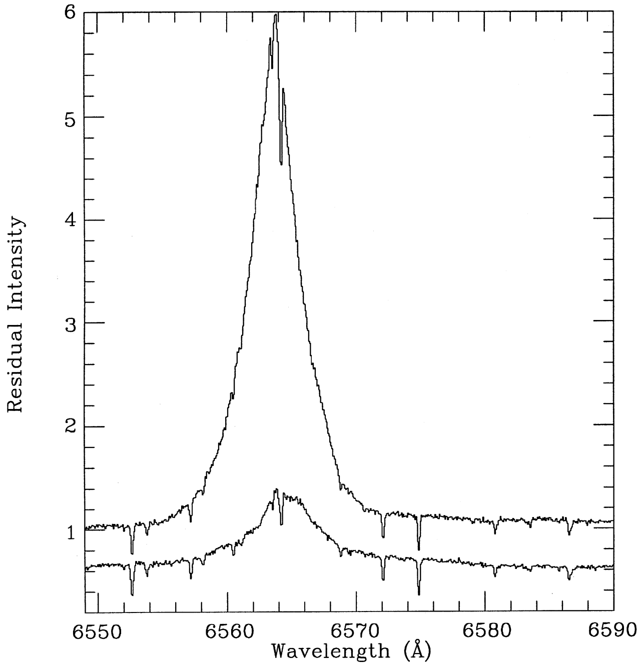

Figure 7. The residual Hα profiles of the two stars after division into 'normal' photospheric profiles of an A2 star (for HD 35187B, top) and A7 star (for HD 35187A, bottom). HD 35187A has been offset by -0.4 in residual intensity for clarity.

Table 2. Equivalent widths and FWHM of the residual Hα emission lines observed in the two components of the HD 35187 binary system.

Star	W_λ (Å)	FWHM (Å)
A	4.7±0.7	7.0±0.5
B	22.1±0.4	5.0±0.5

the Hα emission in HD 35187B, and that the former star is also associated with a source of Hα emission, albeit much weaker than that of its companion. Table 2 gives the equivalent widths and FWHM of these residual Hα emission-line profiles.

Given that both components of the HD 35187 system seem to exhibit Hα emission to some extent, it appears that either, or both, of them could be responsible for the observed temporal variability. As the stars form a binary stystem, and are therefore of comparable age, it is certainly possible that they are both 'active'. This conclusion is supported by the observations of the He I λ5876 line discussed below, although only additional, spatially resolved, spectroscopy of the system will provide a definite answer as to the location of the Hα variability.

4.2 He I λ5876

Fig. 8 shows the He I λ5876 line in both stars. The line is clearly present in both stars, with that in HD 35187B having a slightly greater equivalent width than its lower temperature companion. The measured equivalent widths are

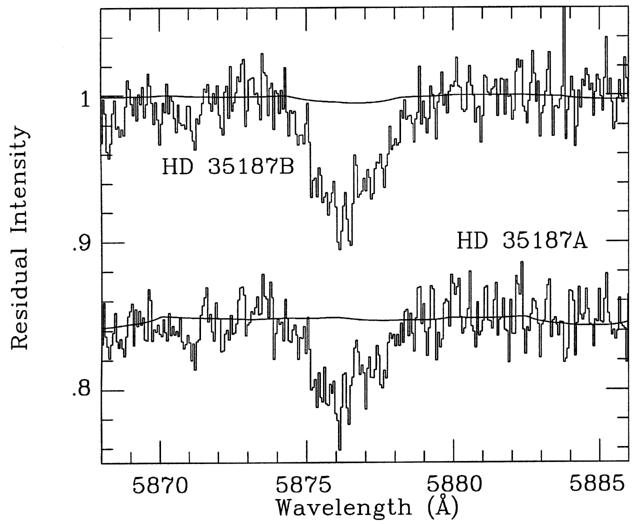

Figure 8. The He I line at 5876 Å for both stars. There is a slight asymmetry in the red wing of both stars, extending to $+200$ km s^{-1} for HD 35187B and $+175$ km s^{-1} for HD 35187A. The spectrum of HD 35187A has been offset for clarity. The solid line represents model photospheric lines for an A2 star (top) and an A7 star (bottom); note that these predict negligible He I absorption for these spectral types.

200 ± 11 mÅ for HD 35187B and 130 ± 10 mÅ for HD 35187A.

He I absorption at 5876 Å is not normally expected to be present in main-sequence stars of this spectral type (model photospheric profiles produced by UCLSYN are shown in the figure for comparison), but it is common in Herbig Ae stars. Although this line was observed by Dunkin et al. (1997b) in the combined spectra of both stars, it was not detected in the observations of Böhm & Catala (1995) or Grady et al. (1996). Therefore, like the Hα emission, the He I absorption appears also to be variable, showing that both stars are prone to spectral variability. There appears to be a slight asymmetry in this line towards both stars, in the form of an extended red wing, which may be indicative of infalling material at high velocities ($+200$ km s^{-1} for HD 35187B and $+175$ km s^{-1} for HD 35187A).

4.3 The Na D and Ca II K lines

The Na I D lines for both stars are shown in Fig. 9, with the model photospheric profiles overlaid. The observed spectra follow the model very well, except in the case of HD 35187B, which appears to have excess absorption to the red of the central core wavelength, and which we will discuss in Section 4.5.2. The Ca II K lines for both stars are shown in Fig. 10, and both show normal photospheric profiles within acceptable variations for A-type stars. The interstellar, and possible circumstellar, Ca K lines will be discussed in Sections 4.4 and 4.5.

4.4 Interstellar absorption lines

Fig. 9 shows that strong, narrow, absorption components are present superimposed on the broad photospheric Na I D lines, which we attribute to interstellar absorption. There is

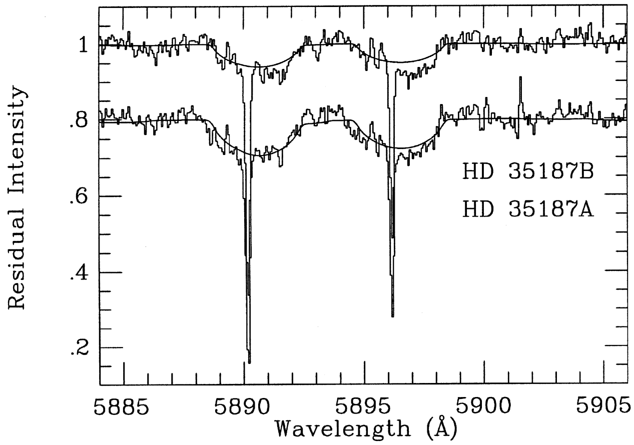

Figure 9. The observed Na I D lines of both stars, with model photospheric line profiles superimposed. The spectrum of HD 35187A has been offset for clarity. The strong, narrow, absorption lines are interstellar, and are discussed further in Section 4.4. Note the apparent excess redshifted absorption in HD 35187B (discussed in Section 4.5).

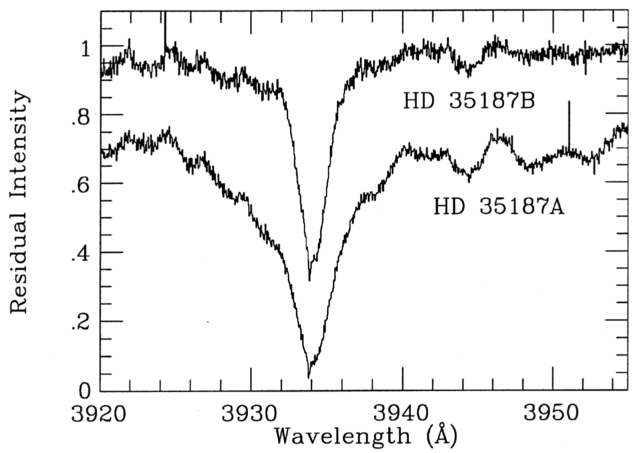

Figure 10. The Ca II K profiles of the two stars. Note the interstellar line visible in the core of the two profiles.

also a weak Ca II K at the same velocity (Fig. 10), which we likewise infer to be interstellar. We also searched for the CH $R_2(1)$ line at 4300.313 Å, but only recorded an upper limit. Table 3 gives the equivalent widths, heliocentric velocities, velocity dispersions (*b*-values) and column densities for these interstellar lines towards HD 35187. For the Na D lines the column density and *b*-value were obtained using the doublet ratio method as formulated by Somerville (1988), adopting the more recent oscillator strengths given by Morton (1991). For the Ca K line, which is clearly resolved in the present data, the parameters were obtained using the line-profile modelling routines in the DIPSO spectral analysis program (Howarth, Murray & Mills 1993). There is no evidence for significant variation in the interstellar line parameters between the two components of the binary system.

As noted in Section 1, HD 35187 lines in the direction of the Taurus dark clouds (see fig. 1 of Zuckerman 1994 for the position of HD 35187 superimposed on the CO map of

Table 3. Interstellar lines observed towards HD 35187. Errors are 2σ values.

Line	W_λ (mÅ)	$v_\odot$ (km s^{-1})	b (km s^{-1})	Log$N$ (cm^{-2})
Na I D_2	123 ± 3	20.4 ± 0.2	2.9 ± 0.3	$12.09^{+0.03}_{-0.02}$
Na I D_1	83 ± 2	20.6 ± 0.2		
Ca II K	21 ± 3	20.3 ± 0.6	5.0 ± 1.5	$11.42^{+0.08}_{-0.10}$
CH $R_2(1)$	≤ 1.5	....	....	≤ 12.25

Ungerechts & Thaddeus 1987). The suggestion that the system is either embedded within the dark clouds (as it would have to be for its assignment as a HAeBe star to be strictly correct), or lies beyond them, is supported by the strengths and velocities of the interstellar lines listed in Table 3, and also by the *Hipparcos* distance of 150 ± 55 pc.

The Taurus clouds have an LSR radial velocity between about $+2$ and $+11$ km s^{-1} (cf. table 1 of Ungerechts & Thaddeus 1987), which corresponds to heliocentric velocities of $+13$ and $+22$ km s^{-1} respectively. The line of sight to HD 35187 passes close to the outer (0.5 K km s^{-1})contour of the Ungerechts & Thaddeus CO map, but approximately mid-way between two discrete molecular condensations. These have average LSR velocities of $+7.6$ and $+7.0$ km s^{-1} ($+18.8$ and $+18.2$ km s^{-1} heliocentric) respectively, which, given the typical velocity spread of several km s^{-1}, are consistent with the measured velocities of the narrow Na I and Ca II absorption lines. Moreover, the moderately high Na I/Ca II column density ratio ($4.7^{+1.6}_{-1.0}$) is consistent with the expected depletion of Ca atoms on to grain surfaces in a moderately dense interstellar environment (cf discussion by Crawford 1992, and references therein). On the other hand, the failure to detect interstellar CH means that the line of sight has not passed through a region of dense *molecular* gas, and this is consistent with the fact that the map of Ungerechts & Thaddeus (1987) shows that the star lies close to the outer boundary of the CO emission.

4.5 Circumstellar absorption lines

One of the objectives of the present work was to search for absorption lines arising in the circumstellar disc presumed to be responsible for the infrared excess of HD 35187 (Section 1). As is well known, strong, time-variable absorption lines are observed in the edge-on disc surrounding the Vega-like star β Pictoris (e.g. Hobbs et al. 1985; Lagrange-Henri et al. 1992; Crawford et al. 1994), and there is evidence for similar circumstellar absorption towards a number of other Vega-like and HAeBe stars (Grady et al. 1996). In the case of β Pic, the temporal variability is generally interpreted as being due to solid, kilometre-sized, bodies ('comets') evaporating as they pass within a few tens of stellar radii of the star (e.g. Beust et al. 1990). If correct, this suggests that β Pic, and by implication other stars showing the same phenomenon, are surrounded by newly formed, or still forming, planetary systems. In their extensive study of the β Pictoris phenomenon in HAeBe stars, Grady et al. (1996; their table 2 and appendix A2) found evidence for redshifted absorption components in a number of UV lines towards HD 35187, and it is clearly of interest to determine if any of these are also present in our optical spectra.

4.5.1 Ca II K line

In addition to the interstellar Ca K component discussed in Section 4.4, careful inspection of the data does reveal evidence for a redshifted narrow absorption component in the spectrum of HD 35187B. However, this component is absent in the spectrum of HD 35187A, which suggests that this component is circumstellar and not interstellar. Fig. 11 shows an expanded view of the core of the photospheric Ca K line for the two components of the HD 35187 system, with the additional circumstellar absorption component towards HD 35187B indicated. A careful inspection of the raw CCD image shows that this feature extends over several rows of the detector, which gives some confidence in its reality. The heliocentric radial velocity of this circumstellar feature is $+54.5 \pm 1.2$ km s^{-1}, and has an equivalent width of 10.6 ± 3.3 mÅ (1σ errors).

4.5.2 Na I D lines

As for the Ca line, careful inspection of the Na D profiles revealed what appears to be excess redshifted absorption in the spectrum of HD 35187B (Fig. 9, Section 4.3). No such absorption is observed in the spectrum of HD 35187A, again suggesting that the absorption is due to circumstellar rather than interstellar material. The velocity range of the absorption is from $+30$ to 110 km s^{-1}, which includes the velocity of the possible Ca K circumstellar line, and also the range of absorption seen in UV lines (see Section 4.5.3). Similar redshifted absorption components in Na D profiles have previously been observed in HAeBe stars (e.g. Graham 1992), and Sorelli, Grinin & Natta (1996) suggested that such absorption may be due to evaporation of planetesimal-sized bodies close to the star. Finally, we note that while, at first sight, it is difficult to explain why the D_1 line seems to exhibit stronger circumstellar absorption than the intrinsically stonger D_2 line (Fig. 9), Hubeny & Heap (1996) have described a mechanism whereby orbiting circumstellar material, covering only a fraction of the stellar disc, can exhibit such an effect (cf. their fig. 7).

4.5.3 UV lines

In order to compare these optical interstellar and circumstellar lines with the UV lines reported by Grady et al. (1996), we have re-extracted the only high-resolution spectrum of this object in the *IUE* archive (LWP 21120). As an example, the region of the Mg II 2803.531-Å line is shown in Fig. 12. As reported by Grady et al., there are three narrow absorption components in the core of this (and other) photospheric absorption lines. Given the uncertainties in the *IUE* wavelength calibration, it is difficult to tell whether or not any of these features occur at the same radial velocity as the narrow absorption components we have found in the Ca K line. If we identify the strongest and least redshifted of the narrow Mg II features with the interstellar line (i.e., $v_\odot = +20.4$ km s^{-1}), the other, presumably circumstellar, components occur at heliocentric velocities of $+70.5$ and $+105.0$ km s^{-1}. Given the poor velocity resolution (25 km s^{-1} FWHM) and signal-to-noise of the *IUE* data, it is possible that our $+54.5$ km s^{-1} Ca K component corresponds with the $+70.5$ km s^{-1} Mg II component. However, as circumstellar absorption components are often variable, we would not necessarily expect observations taken at different times to exhibit components at the same velocities. We do note, however, that the velocity range of the UV absorption line fits very well with the excess absorption seen in the Na D lines. In any case, the detection of optical circumstellar lines towards HD 35187B alone suggests that it is this component of the binary system which gives rise to the redshifted circumstellar lines detected in the UV.

5 DISCUSSION

We have shown that, at least at the epoch of our observations, the bright (net) Hα emission from the HD 35187 system arose from only one of the component stars

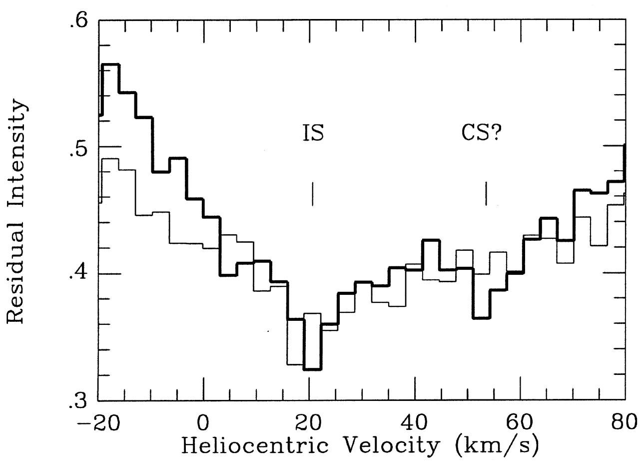

Figure 11. An expanded view of the core of the Ca II K line for HD 35187B (thick line) and HD 35187A (thin line). Note the presence of the interstellar line in both stars, but the presumed circumstellar line is present only towards HD 35187B.

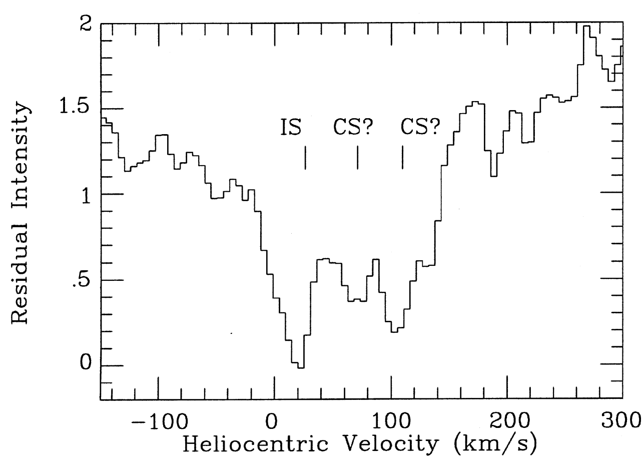

Figure 12. An expanded view of the core of the photospheric absorption in the Mg II 2803.531-Å line. The three narrow interstellar/circumstellar absorption components are marked.

(HD 35187B; Fig. 1). However, the fact that both stars were observed to have anomalously strong (and time-variable) He I λ5876 absorption (Fig. 8), coupled with the evidence for in-filling of the photospheric Hα line in HD 35187A (Fig. 7), suggests that *both* stars exhibit some level of activity. This would be consistent with the fact that both stars, having formed as a binary system, must be of approximately the same (probably very young) age. This activity is also indicated by the clear variability of the Hα line between observations taken over several years (e.g. Zuckerman 1994; Grady et al. 1996; Dunkin et al. 1997b). Various models of the Hα emission which have been used to describe the Hα profiles seen in other HAeBe stars, including magnetic fields interacting with stellar winds, rotating envelopes, and stellar winds with velocity gradients. These models are summarized by Reipurth, Pedrosa & Lago (1996). Here we merely note that, whatever the precise mechanism, they all imply an active circumstellar environment in the HD 35187 system.

The same conclusion follows from our observations of the He I λ5876-Å line. This line is generally expected to form at temperatures of $\sim$10 000 to 30 000 K (Danks & Lambert 1985), and so it cannot be formed in the photosphere of normal A-type stars, whose surface effective temperatures are somewhat cooler. One possible scenario for He I formation is in a circumstellar accretion disc transferring energy to a boundary layer near the stellar surface, producing elevated temperatures similar to that proposed for T Tauri stars (Bertout, Basri & Bouvier 1988). However, this scenario is unlikely to be valid for *both* stars in the HD 35187 system, as we now have quite strong evidence that substantial amounts of gas and dust exist only around HD 35187B (see below). Böhm & Catala (1995) have argued that the formation of the anomalous He I λ5876-Å absorption line must be close to the photosphere, at the base of an expanding chromosphere, since the profiles they observed were similar in width to the rotational broadening observed in the star's photospheric lines. Our data are also consistent with this interpretation, which may suggest a chromospheric origin of this line for the stars in the HD 35187 system also.

The HD 35187 system has a well-known IR excess (e.g. Walker & Wolstencroft 1988; Sylvester et al. 1996) attributed to circumstellar dust. Our search for circumstellar lines revealed a possible circumstellar Ca K component at a heliocentric velocity of $+54.4$ km s^{-1}, and excess redshifted absorption in the Na D lines, but only in the case of HD 35187B. No such circumstellar absorption was found in the spectrum of HD 35187A. Given that we might expect the circumstellar dust to be associated with a gaseous component, our tentative detection of a circumstellar absorption line towards HD 35187B suggests that the IR emission may be associated with this star alone. Moreover, we note that this is also the star which exhibits strong Hα emission (also indicative of circumstellar material), and which appears to suffer from significant ($\approx$0.4 mag) neutral circumstellar extinction. On the basis of this evidence, we argue that HD 35187B is surrounded by a fairly substantial circumstellar disc, and that HD 35187A is not.

Whilst the star has been classed as a Herbig Ae system by Grady et al. (1996) and Böhm & Catala (1995), it has also been identified as a Vega-like star in work by, e.g., Sylvester et al. (1996) and Dunkin et al. (1997a,b), based on the work of Walker & Wolstencroft (1988). The observed fractional IR luminosity (L_{IR}/L_*) of 0.14 (Sylvester et al. 1996) is similar to those of 'classical' HAeBe stars such as BD + 40°4124 and HD 163296 ($L_{IR}/L_* = 0.06$ and 0.26 respectively; Hillenbrand et al. 1992; Sylvester et al. 1996), and the optical spectra of the HD 35187 system do show similarities with HAeBe stars (Dunkin et al. 1997b). Indeed, both components of HD 35187 satisfy most of the HAeBe criteria.

On the other hand, we have shown that these stars are very close to their zero-age main sequence (Fig. 5). Moreover, inspection of the spectral energy distribution of HD 35187 (Sylvester et al. 1996) reveals a dip in its distribution at $\sim$10 μm (a 'double-peaked' SED), similar to that seen by Waelkens, Bogaert & Waters (1994) in their sample of evolved HAeBe stars. Their suggestion is that this type of star is at a stage intermediate between the young HAeBe stars and the β Pic-type stars (the 'classical' Vega-likes). Our work here strengthens this hypothesis, and we argue that the two stars of the HD 35187 system represent transition objects between the true Herbig Ae/Be stars and the less active, prototypical, Vega-like stars.

ACKNOWLEDGMENTS

We thank Sean Ryan for his assistance in obtaining the UCLES spectra of HD 35187, and Paul Crowther and Mike Bessell for performing follow-up observations to check the mapping of position angle of the slit on to the UCLES echellogram. We further thank Mike Bessell for making available his low-resolution spectra of this object. We thank Roger Sylvester for useful discussions on the interpretation of the IR excess of HD 35187, and for a critical review of the original manuscript, Vince Mannings for very helpful advice, and Dr Francesco Palla for kindly making available his pre-main-sequence evolutionary tracks to us. We also thank the referee, Dr C. Waelkens, for making some very helpful comments.

REFERENCES

Allen C. W., 1973, Astrophysical Quantities, 3rd Edn. Athlone Press, London
Bastien U., Finkenzeller U., Jaschek C., Jaschek M., 1983, A&A, 126, 438
Beals C. S., 1950, Pub. Dom. Astrophys. Obs., 9, 1
Bertout C., Basri G., Bouvier J., 1988, ApJ, 330, 350
Beust H., Lagrange-Henri A. M., Vidal-Madjar A., Ferlet R., 1990, A&A, 236, 202
Böhm T., Catala C., 1994, A&A, 290, 167
Böhm T., Catala C., 1995, A&A, 301, 155
Buscombe W., 1995, General Catalogue of MK Spectral Types
Crawford I. A., 1992, MNRAS, 259, 47
Crawford I. A., Spyromilio J., Barlow M. J., Diego F., Lagrange A. M., 1994, MNRAS, 266, L65
Danks A. C., Lambert D. L., 1985, A&A, 148, 293
Dunkin S. K., Barlow M. J., Ryan S. G., 1997a, MNRAS, 286, 604
Dunkin S. K., Barlow M. J., Ryan S. G., 1997b, MNRAS, 290, 165
ESA, 1997, The Hipparcos and Tycho Catalogues. ESA SP-1200
Finkenzeller U., Mundt R., 1984, A&AS, 55, 109
Grady C. A. et al., 1996, A&AS, 120, 157

Graham J. A., 1992, PASP, 104, 479
Gray R. O., Corbally C. J., 1994, AJ, 107, 742
Herbig G. H., 1960, ApJS, 4, 337
Hillenbrand L. A., Strom S. E., Vrba F. J., Keene J., 1992, ApJ, 397, 613
Hobbs L. M., Vidal-Madjar A., Ferlet R., Albert C. E., Gry C., 1985, ApJ, 293, L29
Howarth I. D., Murray J., Mills D., 1993, Starlink User Note, No. 50
Hubeny I., Heap S. R., 1996, ApJ, 470, 1144
Kurucz R. L., 1979, Dudley Obs. Rep., No. 14, p. 271
Kurucz R. L., 1995, in Adelman S. J., Wiese W. L., eds, ASP Conf. Ser. Vol. 78, Astrophysical Applications of Powerful New Databases. Astron. Soc. Pac., San Francisco, p. 205
Lagrange-Henri A. M., Gosset E., Beust H., Ferlet R., Vidal-Madjar A., 1992, A&A, 264, 637
Morton D. C., 1991, ApJS, 77, 119
Oudmaijer R. D., van der Veen W. E. C. J., Waters L. B. F. M., Trams N. R., Waelkens C., Engelsman E., 1992, A&AS, 96, 625
Palla F., Stahler S. W., 1993, ApJ, 418, 414
Reipurth B., Pedrosa A., Lago M. T. V. T., 1996, A&AS, 120, 229
Ryan S. G., Fish A. C., 1995, The UCL Coudé Echelle Spectrographs User Manual. Anglo-Australian Observatory
Schmidt-Kaler T. H., 1982, in Schaifers A., Voigt H. H., eds, Landolt-Börnstein, Numerical Data and Functional Relationships in Sciences and Technology, Group VI, Astronomy, Astrophysics and Space Research, Vol. 2b. Springer-Verlag, Berlin
Shortridge K., 1988, Starlink User Note, No. 86
Smith K. C., 1992, PhD thesis, Univ. London, Chapter 5
Somerville W. B., 1988, Observatory, 108, 44
Sorelli C., Grinin V. P., Natta A., 1996, A&A, 309, 155
Sylvester R. J., Skinner C. J., Barlow M. J., Mannings V. M., 1996, MNRAS, 279, 915
Thé P. S., de Winter D., Pèrez M. R., 1994, A&AS, 104, 315
Ungerechts H., Thaddeus P., 1987, ApJS, 63, 645
Waelkens C., Bogaert E., Waters L. B. F. M., 1994, in Thé P. S., Pérez M. R., van den Heuvel P. J., eds, ASP Conf. Ser. Vol. 62, The Nature and Evolutionary Status of Herbig Ae/Be Stars. Astron Soc. Pac., San Francisco, p. 405
Walker H. J., Wolstencroft R. D., 1988, PASP, 100, 1509
Worley C. E., Douglass G. G., 1996, The Washington Visual Double Star Catalog
Zuckerman B., 1994, in Ferlet R., Vidal-Madjar A., eds, Proceedings of the 10th AIP Astrophysics Meeting, Circumstellar Dust Disks and Planet Formation. Editions Frontieres, p. 131