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# Stellar parameters and evidence of circumstellar activity for a sample of Herbig Ae/Be stars

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## ABSTRACT

**Aims.** We investigate evidence of accretion in a sample of 15 Herbig Ae/Be stars to determine whether these events originate in a remnant gaseous structure from the primordial cloud (rich in hydrogen) or in a metal-rich body (like comets in our Solar System). During such analysis we also determine precise stellar parameters for this sample of stars.

**Methods.** The stars were observed using high resolution spectroscopy ( $R = 48,000$ ). A synthetic photospheric spectrum was constructed and then subtracted from the observed one to obtain the circumstellar component. An iterative procedure was applied to find the stellar parameters that were used to build the synthetic photospheric spectrum.

**Results.** Evidence of circumstellar activity were found in four stars: HD100546, HD142666, HD144432 and HD145718. The presence of redshifted absorption features only in the Balmer lines implies that the accreting material is hydrogen-rich, excluding the possibility that the accretion events might have been created by comet-like bodies. We determined effective temperature, surface gravity, metallicity and the projected rotational velocity for the stars in our sample.

**Key words.** Stars: pre-main sequence, Herbig Ae/Be – Stars: activity – Techniques: spectroscopic – Accretion

## 1. Introduction

Herbig Ae/Be stars (hereafter HAEBE stars) are pre-main sequence, intermediate mass (2 to 10  $M_{\odot}$ ) stars that show high spectroscopic and photometric variability (e.g. Herbig, 1960; Finkenzeller & Mundt, 1984; Thé, de Winter & Pérez, 1994; Vieira et al., 2003). Most of this variability is thought to be due to the interaction of the star with its circumstellar environment, composed of a disc and/or an envelope.

In T Tauri stars accretion and ejection are related to the loss of angular momentum by the system and generally require magnetic fields (i.e. magneto-accretion, Shu et al., 1994; Paatz & Camenzind, 1996). Although there has been evidence of accretion and ejection in HAEBE stars (Natta, Grinin & Tambovtseva, 2000), its correlation with the magnetic field has not been established yet.

Evidence of accretion and ejection can be detected through some characteristic features in the spectrum of the star, such as Redshifted Absorption Components (RACs) and Blueshifted Absorption Components (BACs) (Natta, Grinin & Tambovtseva, 2000; Mora et al., 2002, 2004). In order to find such circumstellar features it is necessary to remove the photospheric contribution from the observed spectrum, which can be done if one is able to reproduce the stellar photospheric spectrum. However,

the high variability level of the HAEBE stars makes it hard to precisely determine the stellar parameters, such as effective temperature ( $T_{\text{eff}}$ ), surface gravity ( $\log g$ ), projected rotational velocity ( $v \sin i$ ) and metallicity ( $[\text{Fe}/\text{H}]$ ). Inaccurate stellar parameters lead to poorly constrained synthetic photospheric spectra.

RACs and BACs are often found in several lines in the optical and near infrared spectra of HAEBE stars (Natta, Grinin & Tambovtseva, 2000; Grinin et al., 2001). In order to better constrain the accretion and ejection episodes, it is important to study the appearance and evolution of these circumstellar absorption components in different lines simultaneously.

We will present the stellar parameters for a sample of 15 HAEBE stars and the evidence of RACs and BACs found in 4 stars. In Section 2 we will present the data reduction procedure. In Section 3 we describe the method used in the determination of the stellar parameters and the results obtained. In Section 4 we present the analysis of the stars that showed evidence of accretion. Some remarks on individual objects are presented in Section 5, and the conclusions are outlined in Section 6.

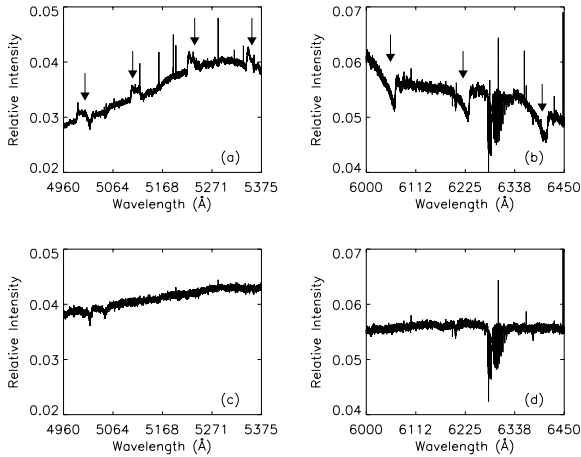
## 2. Observational data

Accretion and ejection are clear signatures of a very active circumstellar environment that causes intense spectral and photometric variability. A sample of 15 HAEBE stars that have

shown this kind of variability was selected from the catalog published by Vieira et al. (2003) as potential candidates to exhibit observable accretion events. This sample was supplemented by a few stars that have had their circumstellar discs imaged (Augereau et al., 1999, 2001; Grady et al., 1996, 2001).

We obtained high resolution ( $\frac{\lambda}{\Delta\lambda} = 48000$ ) échelle spectra, during three nights (7,8 and 9) in May 2002, with the 1.52m ESO telescope in La Silla (Chile), coupled to the FEROS échelle spectrograph, covering a wavelength range from 3800 to 8800 Å. The high resolution and the large spectral range allow the observation of small variations in a large number of lines simultaneously. These two features combined can help us to find correlations between the accretion and/or ejection events in all the observed lines.

The data obtained with the FEROS spectrograph are automatically reduced. However, we found some problems with the automatically reduced flat-field images. These reduction problems created artifacts in the stars' spectra, as shown in panels (a) and (b) of Fig. 1.



**Fig. 1.** Panels (a) and (b) show some artifacts created by a bad reduction of the flat-field image during the automatic procedure. One can see strange spikes (panel a) and absorptions (panel b) in the spectra. Panels (c) and (d) show the same region of the spectra of the same star (HD96042), but now reduced via a manual procedure, where no artifacts can be seen.

To solve this problem we used a set of new routines developed by Dr. Herman Hensberge, of the Royal Observatory of Belgium. Examples of the manually reduced spectra are presented in panels (c) and (d) of Fig. 1. The manual reduction of the data followed standard procedures such: flat-field extraction, wavelength calibration with ThAr lamps and cosmic ray extraction. The major problem with the automatic data reduction concerns the choice of the order template. If the star is too bright or too dim, the automatic procedure is not able to find the correct échelle orders because the used template is not the ideal one. The same problem can also be present during the reduction of flat-field and ThAr images. It is solved through the use of new order templates, which can be constructed based on the observed data.

Table 1 presents the observational log for the 15 selected HAEBE stars. Three stars were observed at least 5 times per night (HD141569, HD144432 and HD163296) to search for short timescale spectral variabilities. Four stars presented

evidence of circumstellar activity: HD100546, HD142666, HD144432 and HD145718.

**Table 1.** Observational data. The columns present the star's identifier (PDS and HD catalogs), right ascension ( $\alpha$ ), declination ( $\delta$ ), number of observed spectra, exposure time (in seconds), magnitude in the V band and the average signal-to-noise ratio, respectively.

PDS	HD	$\alpha(2000)$	$\delta(2000)$	#	Exp.(s)	V	S/N
303	87403	10 02 51.5	-59 16 54.7	2	900	9.24	106
327	96042	11 03 40.6	-59 25 59.1	3	900	8.51	132
339	100453	11 33 05.6	-54 19 28.5	3	600	7.79	108
340	100546	11 33 25.4	-70 11 41.2	3	500	6.70	137
057	101412	11 39 44.5	-60 10 27.7	3	1800	9.28	98
069	Hen 3-949	13 57 43.1	-39 58 45.0	3	2400	9.70	65
395	139614	15 40 46.4	-42 29 53.5	3	900	8.25	120
398	141569	15 49 57.8	-03 55 16.4	14	300	7.00	95
076	142666	15 56 40.0	-22 01 40.0	3	1200	8.81	120
078	144432	16 06 58.0	-27 43 09.8	15	300	8.16	80
080	145718	16 13 11.6	-22 29 06.6	3	900	8.98	110
473	163296	17 56 21.3	-21 57 21.9	20	300	6.87	116
514	169142	18 24 29.8	-29 46 49.4	3	600	8.15	121
545	174571	18 50 47.2	08 42 10.1	3	1500	8.89	118
564	179218	19 11 11.3	15 47 15.6	3	400	7.20	113

### 3. Stellar parameters

The search for accretion and ejection events in HAEBE stars often requires subtraction of the photospheric contribution from the observed spectrum. This task can be done if we are able to create synthetic spectra based on the stellar parameters. However, the stellar parameters of young stars are very difficult to obtain, due to the high level of activity. In order to obtain such parameters we applied the method described in the following subsections to all stars of our sample.

#### 3.1. Outline of the method

The method used to find the stellar parameters of each star is similar to the one described by Merin et al. (2004) and is based on the following steps:

1. Construction of synthetic photospheric spectra for the Balmer lines, using an initial input for the values of  $T_{\text{eff}}$ ,  $v \sin i$  and  $[\text{Fe}/\text{H}]$  and several values of  $\log g$ ;
2. Measurement of the Balmer line profiles width at an intensity level of 0.8 of the continuum ( $I = 0.8$ );
3. Use of this width as the independent variable in a linear fit procedure to find the best value for  $\log g$ ;
4. Use of the best value of  $\log g$ , found in the previous step, to find the best values of  $T_{\text{eff}}$ ,  $v \sin i$  and  $[\text{Fe}/\text{H}]$  that fit the metallic lines of each star. The metallic lines were chosen among those that remained constant during all the observations and are called “pure photospheric lines”;
5. Use these new values of  $T_{\text{eff}}$ ,  $v \sin i$  and  $[\text{Fe}/\text{H}]$  as input to find the  $\log g$  again until convergence is achieved.

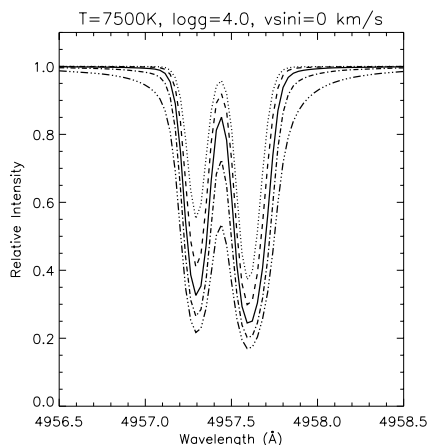
The Balmer lines are selected to find  $\log g$  because their wings are very sensitive to changes in the star's surface gravity, while the metallic lines are used because they are extremely sensitive to changes in the star's temperature and metallicity. The measurement of the width of the Balmer line profiles at an intensity of 0.8 of the continuum avoids small subtleties due to the normalization procedure.

### 3.2. Fit of parameters

To fit the stellar parameters we divided our sample into three groups.

- Group 1:  $T_{\text{eff}} < 8,000\text{K}$ ; where the relationship between the Balmer line width and  $\log g$  is not linear;
- Group 2:  $9,000 < T_{\text{eff}} < 15,000\text{K}$ ; where the photospheric lines are clearly visible and there is a linear relationship between the Balmer line width and  $\log g$ ;
- Group 3:  $T_{\text{eff}} > 15,000\text{K}$ ; where the almost complete absence of photospheric lines prevents us from applying the proposed method.

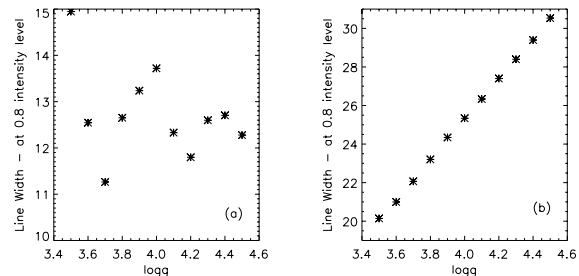
We have made use of the SME code, by Valenti & Piskunov (1996), to build the grids of synthetic spectra. This code also allows us to vary the following parameters:  $T_{\text{eff}}$ ,  $\log g$ ,  $\nu \sin i$ ,  $[\text{Fe}/\text{H}]$ , micro and macro turbulent velocities and radial velocity. Following Dunkin et al. (1997), parameters such as micro and macro turbulent velocities were kept constant at 2 and 5  $\text{km s}^{-1}$ , respectively. As a starting point we used the  $T_{\text{eff}}$  values determined by Vieira et al. (2003) and solar metallicity ( $[\text{Fe}/\text{H}] = 0.0$ ). The radial velocity can be estimated by the code and its value was left free during the fit. The  $\nu \sin i$  value was found by leaving it as a free parameter at the beginning of the calculations. The convergence is very fast and only minor changes (less than 1  $\text{km s}^{-1}$ ) are necessary at the end of the calculations. The metallicity of the star, represented by the  $[\text{Fe}/\text{H}]$  parameter, is very important because it can change the values of  $T_{\text{eff}}$  and  $\log g$ . Fig. 2 shows the influence of different values of  $[\text{Fe}/\text{H}]$  in a synthetic photospheric spectrum of fixed  $T_{\text{eff}}$  and  $\log g$ . Based on such variability we decided to leave  $[\text{Fe}/\text{H}]$  as a free parameter during the fit.



**Fig. 2.** Example of the  $[\text{Fe}/\text{H}]$  influence on the Fe I 4957 photospheric line profile. All profiles were generated with the following physical parameters:  $T_{\text{eff}} = 7500\text{K}$ ,  $\log g = 4.0$  and  $\nu \sin i = 0 \text{ km s}^{-1}$ . Solid line  $[\text{Fe}/\text{H}] = 0.0$ , dotted line  $[\text{Fe}/\text{H}] = -1.0$ , dashed line  $[\text{Fe}/\text{H}] = -0.5$ , dashed-dotted line  $[\text{Fe}/\text{H}] = +0.5$  and dashed-dotted-dotted line  $[\text{Fe}/\text{H}] = +1.0$ . As one can see the profile gets deeper as the metallicity increases.

There is a difference in the method used to fit  $\log g$  for the Group 1, because the variation of the width of the Balmer lines, in this case, is not linear with the  $\log g$  value, as can be seen in Fig. 3. Therefore we selected the values of  $\log g$  that produced synthetic spectra whose width, measured at an intensity level of 0.8, differed by no more than 1% from the width of the observed

Balmer lines at the same intensity level. This procedure yields many  $\log g$  values for a single line width. The only way to find the best value, and its error, is to build a grid of synthetic spectra for each  $\log g$  value, varying the values of  $T_{\text{eff}}$ ,  $\nu \sin i$  and  $[\text{Fe}/\text{H}]$ . For Group 1 stars the error of each parameter is larger than for Group 2 stars, due to uncertainties in the  $\log g$  determination.



**Fig. 3.** Behavior of  $\log g$  for Groups 1 and 2. Panel (a) shows the  $\text{H}\gamma$  line width versus  $\log g$  for a star (HD142666) of Group 1 ( $T_{\text{eff}} < 8,000\text{K}$ ) and panel (b) for a star (HD100546) of Group 2 ( $9,000 < T_{\text{eff}} < 15,000\text{K}$ ). In the second case the linear correlation is clear, whereas there is no correlation in the first case.

### 3.3. Error determination and results

The determination of precise parameters for young stars is a difficult task because the line profile can change over short periods. As an example, some of the lines of HD141569 are so variable (e.g. Mg II 4481Å) that it is hard to find stable lines to determine the photospheric parameters. In some cases the high  $\nu \sin i$  merges the lines, making it much more difficult to obtain precise fit parameters.

Pre-main Sequence stars show large photometric variations that may lead to wrong parameters if one relies only on photometric data. To overcome these problems we used high S/N spectra with large wavelength range and we have chosen only lines that were stable during our observations and those that were symmetric. By symmetric we mean lines that do not show clear evidence of RACs and BACs.

For each group of stars there is a different way to determine the error of the parameters. Since  $\log g$  for Group 2 is well determined, the error calculation follows the steps below:

- a grid of synthetic photospheric spectra is constructed, keeping  $\log g$  constant and varying  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$ . Different sets of solutions are created by different pairs of  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$ ;
- a solution ( $T_{\text{eff}}$ ,  $\log g$  and  $[\text{Fe}/\text{H}]$ ) is acceptable if it is not different by more than 1% from the observed spectrum;
- some sets of solutions are discarded based on the presence or absence of helium and metallic lines;
- the error for each parameter represents its possible value within the accepted set of solutions.

To obtain the errors for Group 1 stars it is necessary to check for degenerate solutions, as follows:

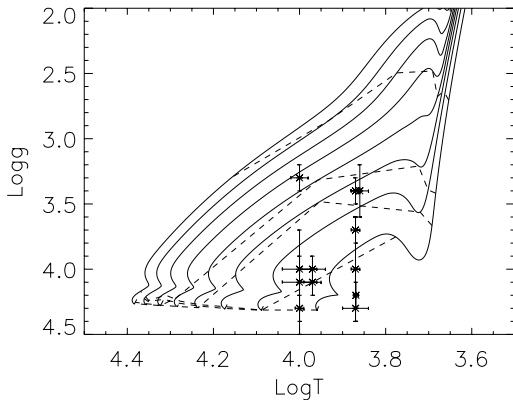
- for each possible value of  $\log g$  we construct a grid of synthetic spectra, varying  $T_{\text{eff}}$  and  $[\text{Fe}/\text{H}]$ ;
- we select the sets of parameters ( $\log g$ ,  $T_{\text{eff}}$ ,  $[\text{Fe}/\text{H}]$ ) that fit the observed spectra;

- based on some criteria (e.g. presence and fit of metallic lines) we exclude some sets of values. As an example, for an F0 star that presents several metallic lines, pairs of  $T_{\text{eff}}$  and  $\log g$  such as  $T_{\text{eff}} = 12,000$  K and  $\log g = 5.0$ , or  $T_{\text{eff}} = 4,000$  K and  $\log g = 3.0$  do not represent good solutions and are discarded;
- the acceptable sets of values are used as the final values and errors.

For Groups 1 and 2, we searched for solutions varying the following parameters within the respective intervals,  $\log g \pm 1.0$  dex,  $v \sin i \pm 5$  km s<sup>-1</sup> and  $[\text{Fe}/\text{H}] \pm 2.0$  dex. The only difference is the temperature interval, for Group 1 we used  $T_{\text{eff}} \pm 1,000$  K while for Group 2 we used  $T_{\text{eff}} \pm 2,000$  K. The maximum and minimum values used during this procedure do not correspond to the errors themselves, they just define an interval within which we searched for degenerate solutions.

The parameters obtained for each star are listed in Table 2. Some values agree very well with the most recently published values, although a few discrepancies exist for some objects, such as HD169142, presented in section 5.

In order to check the evolutionary status of the HAEBE stars we used the  $T_{\text{eff}}$  and  $\log g$  values to plot these stars in an HR diagram, together with a set of PMS evolutionary tracks, as shown in Fig. 4. The evolutionary tracks were computed using the ATON 2.0 stellar evolution code (Mazzitelli, 1989; Mazzitelli, D’Antona & Caloi, 1995; Ventura et al., 1998). Details can be seen in Vieira et al. (2003).



**Fig. 4.** Evolutionary tracks from 2 up to  $7 M_{\odot}$  with steps of  $1 M_{\odot}$ . The isochrones are plotted with dashed lines, starting at 0.25 Myr, at the top of the HR diagram, until 10 Myr, bottom of the tracks. The stars are plotted with the respective error bars.

We can divide our sample in three groups in the HR diagram of Fig. 4. The first group contains very young stars with ages below 1.0 Myr (HD87403, HD144432 and HD145718). The second group is composed of stars with ages between 1.0 and 5.0 Myr (HD101412, HD163296, HD169142 and HD179218). And the third group with more evolved stars with ages above 5.0 Myr (HD100453, HD100546, HD139614, HD141569, HD142666). We have not found any correlation between age and circumstellar activity since the stars that presented evidence of accretion have ages spread between 0.5 and 10 Myr.

#### 4. Accretion episodes

To quantify the absorption produced by the circumstellar environment we followed the definitions made by Natta, Grinin & Tambovtseva (2000). The depth of the circumstellar absorption component ( $\tau$ ) is defined as:

$$\tau = 1 - \frac{F_{\text{obs}}}{F_{\text{syn}}} \quad (1)$$

where  $F_{\text{obs}}$  and  $F_{\text{syn}}$  represent respectively the observed and the synthetic photospheric intensity at peak wavelength. The above definition shows us that when  $\tau = 1$  the circumstellar line is saturated and when  $\tau = 0$  there is no circumstellar contribution.

As suggested by Natta, Grinin & Tambovtseva (2000), the RACs may originate in a gaseous structure falling from the disc (or envelope) towards the star or in a comet-like body in a star-grazing orbit. In the first case we expect to see RACs in the Balmer lines and in some metallic lines such as Na I D and Ca II. On the other hand, we expect to see RACs with a much larger optical depth in metallic lines than in the Balmer lines when a comet-like body evaporates in its star-grazing orbit towards the star, because such solid bodies should be highly hydrogen depleted. However, while we often see RACs in the Balmer lines of our stars, we do not observe any RAC in metallic lines in our sample. This can be seen in Fig. 5, where we show the observed (solid lines) and synthetic (dashed lines) spectra of the Na I D1 and Fe I (4957Å) regions obtained in our last observing night (JD=2452404). These lines were observed simultaneously with the Balmer lines shown in Fig. 7. We see that at JD=2452404 we have the presence of a strong redshifted absorption component in all the Balmer lines, while no RACs are seen in the metallic lines of Fig. 5.

It is possible to study the dynamics of the accretion if one is able to obtain several spectra in which there is evidence of accretion (RACs). The behavior of the velocity of the RACs suggests whether the gas is falling towards the star driven or not by magnetic field lines. If the star is photometrically variable it is necessary to flux calibrate the spectra so one can determine if the variation of the line depth is due to a variation in the star’s total flux. We do not have simultaneous photometry so we cannot calibrate the spectra, however based on the variation of the RACs’ radial velocity it is possible to determine the dynamics of the material falling towards the star.

Four out of twelve stars with stellar parameters listed in Table 2 are photometrically stable according to the present literature (HD87403, HD100453, HD144432 and HD 169142), five are photometrically variable (HD100546, HD141569, HD142666, HD145718 and HD163296) and three do not present enough information in the literature to confirm any photometric behaviour.

The next subsections will show our analysis for three HAEBE stars that showed evidence of accretion.

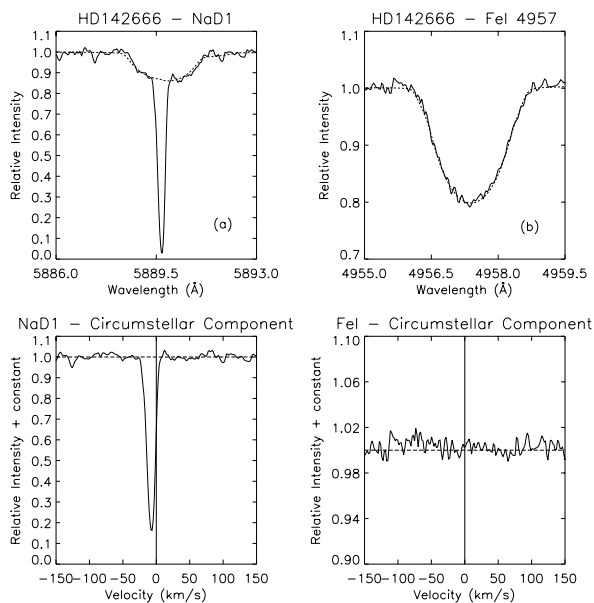
##### 4.1. HD142666

This star, catalogued as A8V by SIMBAD, is located at the star forming region Sco R1 (following Vieira et al., 2003) at a distance of 100 – 160 pc, according to Racine (1968). The stellar parameters found in the literature range from an A5V ( $T_{\text{eff}} = 8250$  K and  $\log g = 4.5$ , Malfait, Bogaert & Waelkens, 1998; Meeus, Waelkens & Malfait, 1998) to A8Ve ( $T_{\text{eff}} = 7150$  K and  $\log g = 4.4$ , Dunkin et al., 1997).

The parameters found by Meeus, Waelkens & Malfait (1998) were based on photometric observations in the optical and ultra-

**Table 2.** Stellar parameters. The columns present the star’s identifiers,  $T_{\text{eff}}$  and error,  $v \sin i$  and error,  $\log g$  and error and the metallicity  $[\text{Fe}/\text{H}]$  and error.

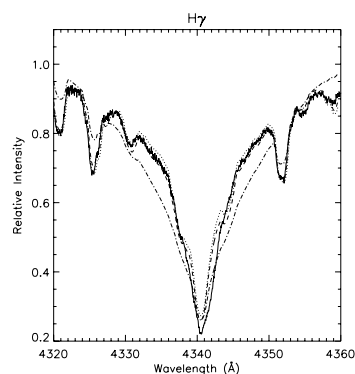
PDS	HD	$T_{\text{eff}}$ (K)	$\Delta T_{\text{eff}}$	$v \sin i$ ( $\text{km s}^{-1}$ )	$\Delta v \sin i$	$\log g$	$\Delta \log g$	$[\text{Fe}/\text{H}]$	$\Delta[\text{Fe}/\text{H}]$
303	87403	10000	500	105	5	3.3	0.1	0.0	0.3
339	100453	7400	400	48	2	4.2	0.1	0.3	0.3
340	100546	10000	1000	60	5	4.2	0.2	-1.4	0.2
057	101412	10000	1000	7	1	4.1	0.4	-1.0	0.2
395	139614	7400	200	25	1	4.0	0.4	-0.5	0.1
398	141569	10000	200	230	10	4.3	0.1	-0.4	0.1
076	142666	7500	500	66	3	4.3	0.1	0.2	0.2
078	144432	7300	300	80	5	3.4	0.2	0.3	0.2
080	145718	7500	200	115	5	3.4	0.1	0.0	0.1
473	163296	9400	200	130	10	4.1	0.1	0.5	0.1
514	169142	7500	200	55	5	3.7	0.1	-0.5	0.1
564	179218	9500	500	72	3	4.0	0.1	-0.5	0.1

**Fig. 5.** Example of metallic lines that do not present RACs. In the top panels the dashed line represents the synthetic model and the solid line represents the observed spectrum, while in the bottom panels the solid line represents the circumstellar component and the dashed line represents the intensity level at 1.0. Panel (a) shows the Na I D1 (5889.95 Å) where it is possible to see the narrow interstellar component. We notice that the synthetic spectrum is a very good fit to the photospheric one. The circumstellar component is showed in the lower panel. Panel (b) presents the Fe I (4957 Å) where we see that the synthetic spectrum fits the photospheric one very well. In the lower panel we can see the circumstellar component where no RAC was detected.

violet regions together with the fit of atmosphere models while Dunkin et al. (1997) have made a spectral classification using échelle spectra. Fig. 6 shows the comparison between the stellar parameters found by us and those found in the literature. As can be seen the values from Dunkin et al. (1997) are in good agreement with ours, but disagree with the results by Meeus, Waelkens & Malfait (1998) and the SIMBAD database.

HD142666 is photometrically variable comparing data in the literature (Slawson, Hill & Landstreet, 1992; Malfait, Bogaert & Waelkens, 1998; Oudmaijer et al., 2001; Vieira et al., 2003). The amplitude of variation can reach up to  $\sim 1.0$  in  $V$  on a time scale of months (Meeus, Waelkens & Malfait, 1998). Kurtz & Müller (2001) also reported that this star presents  $\delta$  Scuti pulsations with

a period of 61 minutes and an amplitude of 0.01 magnitude in the B filter. Since we do not have simultaneous photometry, it is not possible to determine whether the changes in the absorption depths are due to changes in the star’s total flux. We will restrict our analysis to the changes in the RACs’ radial velocity.

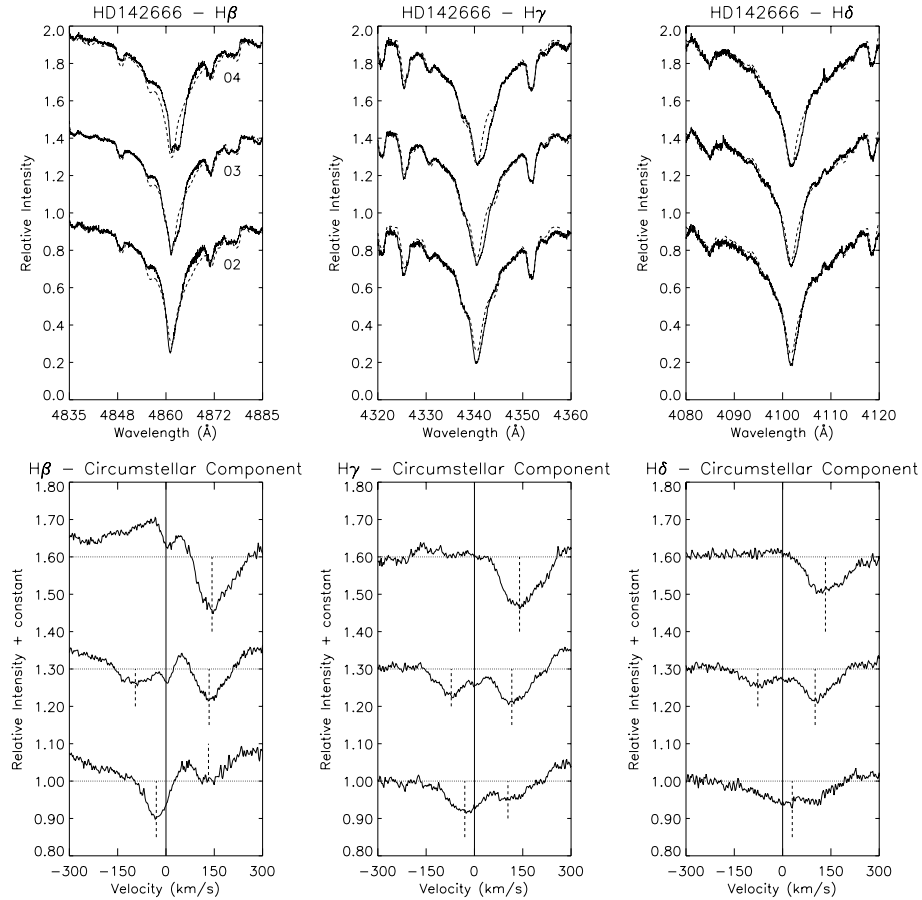
**Fig. 6.** Comparison between our results and the results from the literature for HD142666. The synthetic spectrum obtained with the parameters we determined is shown as a dashed line, the one calculated with Meeus, Waelkens & Malfait (1998) values correspond to the dotted line and the stellar parameters obtained by Dunkin et al. (1997) yield the synthetic spectrum shown as a dot-dashed line.

We have found RACs only in the Balmer lines such as  $H\beta$ ,  $H\gamma$  and  $H\delta$ , as shown in Fig. 7, where the top panels show the observed and synthetic spectrum for each line and the bottom ones present the respective circumstellar components. The RACs are marked, in the bottom panels, by dashed vertical lines. The velocities of the RACs and BACs are listed in Table 3.

**Table 3.** Velocities of the RACs and BACs found in HD142666.

Date	$H\beta$	$H\gamma$	$H\delta$
	$V$ ( $\text{km s}^{-1}$ )	$V$ ( $\text{km s}^{-1}$ )	$V$ ( $\text{km s}^{-1}$ )
07 May 2002	132	104	30
	-30	-30	
08 May 2002	134	116	101
	-95	-72	-77
09 May 2002	143	140	133
	7		

$H\beta$  and  $H\gamma$  lines exhibited clear evidence of RACs in all the nights observed. The  $H\delta$  line also presented evidence of accre-



**Fig. 7.** Evidence of accretion and ejection of matter found in the circumstellar component of the Balmer lines of HD142666. The solid curves represent the observed spectra while the dashed curves represent the synthetic line profile. The top panels show the observed and synthetic Balmer lines, from left to right we have H $\beta$ , H $\gamma$  and H $\delta$ . The bottom panels show the circumstellar components of the Balmer lines. In the circumstellar component we also plot a straight line to mark the star's zero velocity reference, dashed lines to mark the RACs and BACs and a dotted line to show the zero absorption level. In each panel the spectra are ordered from bottom to top according to the date of observation (JD-2452400), as shown in the H $\beta$  panel.

tion but the absorption feature found in the first night is more complex than the features observed on the other nights. From Table 3 one may see that the RACs' velocity increases with time. Such behavior might be explained by the assumption that the gaseous structure is falling towards the star. The velocity was taken as the center of a Gaussian curve that fits the circumstellar feature. The material falling towards the stars seems to be rich in hydrogen, since RACs were observed only in the Balmer lines.

The BACs observed in HD142666 showed some similarities in H $\beta$  and H $\gamma$  lines. Once more, the complex feature observed in the first night in the H $\delta$  line prevents us from performing a better analysis. From the values of Table 3 we see that the BACs' velocities increase, in modulus, from the first to the second night.

#### 4.2. HD145718

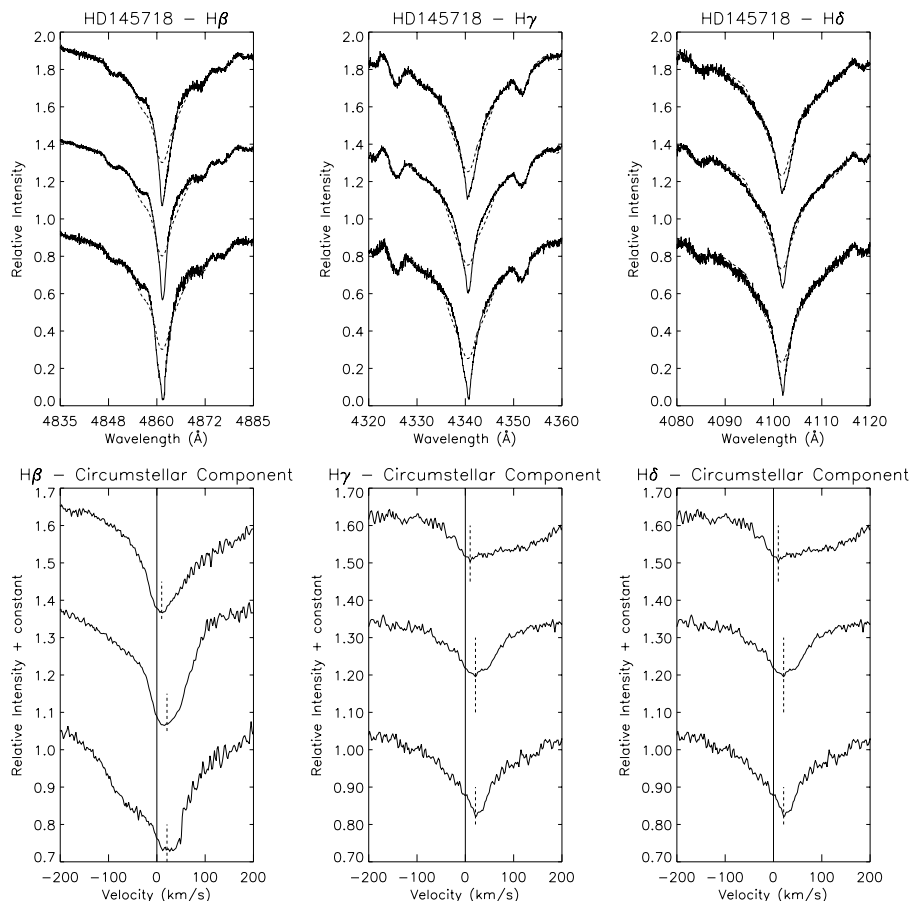
This star, also known as V718 Sco, is catalogued as an A8III/IV by SIMBAD, its distance is  $130 \pm 20$  pc (Perryman et al., 1997) and it is likely associated with the  $\rho$  Oph cloud (110 – 160 pc, e.g. Franco, 1990). It was classified by Koch, Sobieski & Wood (1963) as an eclipsing binary of Algol type but following Friedemann, Gürtler & Löwe (1996) and van der Veen et al. (1994) its classification as a binary is still uncertain and more observations are required. HD145718 is photometrically

variable, presenting a small magnitude variation ( $\sim 1\%$  in V) comparing data in the literature (Wolf & Kern, 1983; Slawson, Hill & Landstreet, 1992; Vieira et al., 2003). We will therefore assume that the photometric variability will not affect our analysis of the RACs optical depth.

We have found evidence of accretion in the Balmer lines, mainly H $\beta$ , H $\gamma$  and H $\delta$ , as shown in Fig. 8. The velocities of the RACs, obtained in the same manner as for HD142666, are listed in Table 4, together with the circumstellar absorption depth ( $\tau$ ).

In all lines, both the velocity and  $\tau$  decrease with time. This behavior is not straightforwardly explained in a scenario where the RACs originate from accreting material that falls towards the star. However, such behavior might be explained assuming that the gaseous structure is falling into the star driven by dipolar magnetic field lines. The RAC's velocity is the projected velocity in our line of sight and as such it decreases near the star for the case of a line of sight parallel to the disc (near edge-on system), as shown in Fig. 9.

Following Shu et al. (1994) we calculated the truncation radius of the inner disc ( $R_t$ ), from where the material falls into the star via magnetic field lines. The star's radius ( $R_\star = 5.7R_\odot$ ) was calculated based on our  $\log g$  value and the mass ( $M_\star \sim 3M_\odot$ ) was determined using the ATON 2.0 stellar evolution code. We used a magnetic field strength of  $B_\star = 1\text{kG}$ , even knowing that there are no observational measurements of such a strong mag-



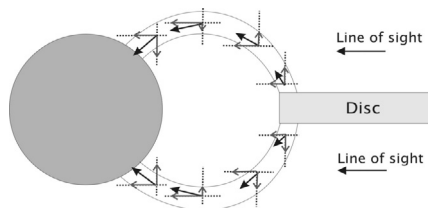
**Fig. 8.** Same caption as Fig. 7 but for the HAEBE star HD145718.

**Table 4.** Velocities and  $\tau$  values of the RACs found in HD145718.

Date	H $\beta$		H $\gamma$		H $\delta$	
	V (km s $^{-1}$ )	$\tau$	V (km s $^{-1}$ )	$\tau$	V (km s $^{-1}$ )	$\tau$
07 May 2002	27	0.90	27	0.86	21	0.76
08 May 2002	16	0.77	16	0.60	21	0.45
09 May 2002	12	0.77	4	0.59	10	0.42

netic field in HAEBE stars. Young early-type stars are not expected to have magnetic fields due to a dynamo type of activity as strong as those measured in T Tauri stars, but some main sequence A stars actually do show magnetic fields of the order of kG (Borra et al., 1982). Only recently was the longitudinal magnetic field measured at a level higher than  $3\sigma$  by Hubrig et al. (2006) and Wade et al. (2005), obtaining fields of the order of  $10^2$  G. We also noted that values of  $B_*$  ranging from 100 G to 10 kG do not change significantly the value of the infall velocity.

Muzerolle et al. (2004), however, have successfully fitted magnetospheric accretion models to the Balmer and NaD emission lines of UX Ori (an A2 star), suggesting that magnetospheric accretion could be important in intermediate mass objects. Muzerolle et al. (2004) also showed that models of the accretion shock can explain the observed excess flux in the Balmer discontinuity for a large number of HAEBE stars, implying mass accretion rates smaller than  $\sim 10^{-7} M_{\odot} \text{ yr}^{-1}$ . We then adopted  $\dot{M} \sim 10^{-8} M_{\odot} \text{ yr}^{-1}$ , as a reasonable value for a HAEBE star. With the above parameters we obtained a truncation radius of  $R_t \sim 13 R_{\odot}$ . Assuming that the material starts its fall from rest and free falls onto the star via magnetic field lines we evalu-



**Fig. 9.** Example of magnetoaccretion where we see the tubes leaving the disc surface and reaching the star. The trajectory followed by the gas toward the star is represented by the arrows. The decomposition of the velocity vector in the line of sight shows that such accretion model qualitatively explains the observed behavior of the RACs.

ate its final velocity as  $\sim 430 \text{ km s}^{-1}$ . The geometry of the accretion process, indicated by Fig. 9, together with the supposed line of sight, shows that during the fall there is a point where the projected velocity equals the infall velocity, and after that the projected velocity always decreases. From this point to the stellar surface, we estimated an infall time of about half a day. Thus, qualitatively, the magneto-accretion model could explain the behavior of the RACs for this star. However, quantitatively, the model shows that the time necessary for infall is much less than the observed time. Estimates of individual mass accretion rates and of the magnetic field strength are, however, needed for a more accurate evaluation of the importance of magnetospheric accretion to HAEBE stars.

### 4.3. HD100546

This Herbig Be star is classified as B9.5Ve, at a distance of  $103 \pm 6$  pc, with an estimated age  $\sim 10$  Myr, following van den Ancker et al. (1997). Our results, mainly the  $\log g$  value, indicate an age between 5 and 10 Myr. The determination of  $\log g$  for this star is shown in panel b of Fig. 3. A circumstellar disc was revealed by visible and infrared imaging (Grady et al., 2001; Augereau et al., 2001) and evidence of accretion were reported by Vieira, Pogodin & Franco (1999). Our results indicate that this star is deficient in Fe which corroborates the results from Acke & Waelkens (2004). This star is photometrically constant within  $\sim 1\%$  in V, by comparing data in the literature (Hu, Thé & de Winter, 1989; Slawson, Hill & Landstreet, 1992; Malfait, Bogaert & Waelkens, 1998; de Winter et al., 2001; Vieira et al., 2003). We will therefore assume that the photometric variability will not affect our analysis of the RACs optical depth.

Figure 10 shows the spectra and circumstellar components for H $\gamma$  and H $\delta$  Balmer lines. Evidences of ejection are clearly visible in the blue circumstellar component, for all the nights. The second night also shows evidence of accretion in both lines. The velocity and  $\tau$  values are presented in Table 5.

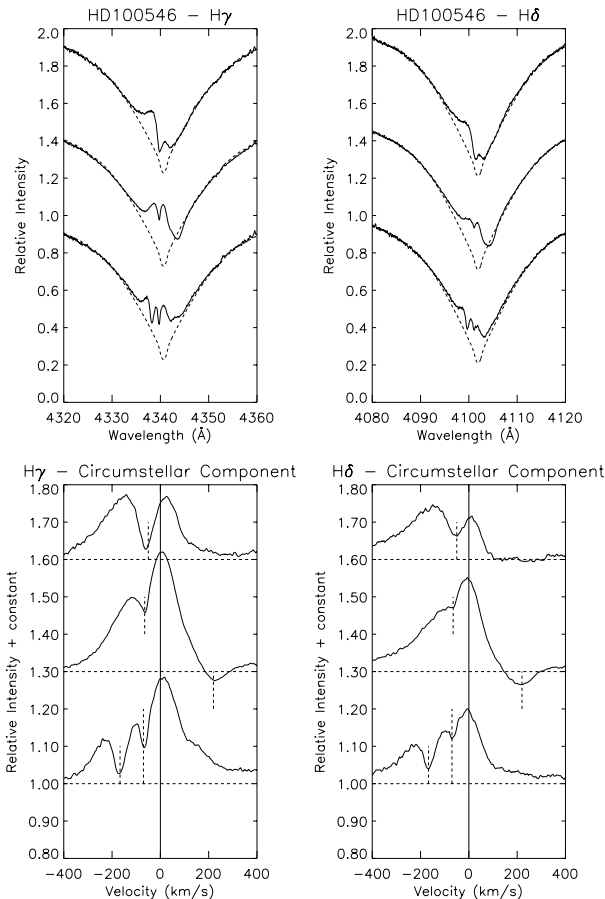


Fig. 10. Same caption as Fig. 7 but for the HAEBE star HD100546.

The RACs and BACs present in our observations of HD100546 do not show any systematic behavior, so it is not possible to establish any coherent formation scenario for such structures based only on our 3 spectra. Higher temporal resolution is necessary in this case.

Table 5. Velocities and  $\tau$  values of the RACs and BACs found in HD100546.

Date	H $\gamma$		H $\delta$	
	V(km s $^{-1}$ )	$\tau$	V(km s $^{-1}$ )	$\tau$
07 May 2002	-172	-0.07	-167	-0.11
	-66	-0.30	-70	-0.44
08 May 2002	225	0.06	220	0.09
	-63	-0.50	-65	-0.65
09 May 2002	-63	-0.08	-50	-0.25

## 5. Remarks on individual stars

**HD101412:** This star has the lowest  $v \sin i$  value of all the sample (see Table 2), which suggests that we see it almost pole on. It is classified as B9.5 V in the SIMBAD database but we estimate it to be an A0 III/IV star, based on our temperature and surface gravity values.

**HD139614:** The parameters we have found for this star do not agree with the parameters from Dunkin et al. (1997) ( $T_{\text{eff}} = 8250\text{K}$ ,  $\log g = 4.2$ ,  $v \sin i = 24 \text{ km s}^{-1}$ ,  $[\text{Fe}/\text{H}] = -0.16$ ) and Acke & Waelkens (2004) ( $T_{\text{eff}} = 8000\text{K}$ ,  $\log g = 4.5$ ,  $v \sin i = 24 \text{ km s}^{-1}$ ,  $[\text{Fe}/\text{H}] = -0.3$ ). Their temperature does not fit the observed lines, in a similar way to HD169142 as shown in Fig. 11.

**HD144432:** An extensive discussion about this star was provided by Pérez et al. (2004); it is classified as A9/F0V while our results show a discrepancy in the luminosity class, given its  $\log g$ . Pérez et al. (2004) also found a probable companion, of K type, for this star, through optical and near-IR imaging. We also corroborate the Li I 6707.8 Å detection in the HD144432 spectra, observed by Pérez et al. (2004), which adds support to the pre-main sequence nature of this star. We have found BACs in the Balmer lines together with large variations in other lines, such as Mg II 4481 Å, He I 5876 Å and Na I D1. We will use our 15 spectra, collected in this mission, to perform a detailed analysis together with the correlation between the variable lines and a model able to explain such variations. Such work will be presented in a future paper.

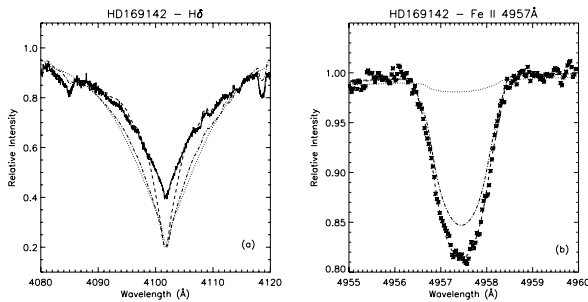
**HD169142:** This star has a spectral type B9Ve listed in the SIMBAD database, A5Ve by Dunkin et al. (1997) (spectral classification with échelle spectra) and a spectral type A9III/IVe from our fit and from Vieira et al. (2003). As an example we show the parameters we have found for this object together with the values found in the literature in Fig. 11. It can be seen that the values taken from SIMBAD and from Dunkin et al. (1997) do not fit the observed lines. The absence of He I lines indicates that this star does not have a spectral type B9V as also noted by Dunkin et al. (1997).

## 6. Conclusions

The method described in this work has enabled us to obtain the stellar parameters,  $T_{\text{eff}}$ ,  $\log g$ ,  $v \sin i$  and  $[\text{Fe}/\text{H}]$ , for a sample of 15 HAEBE stars. For some objects it was the first time that such parameters were obtained. Synthetic photospheric spectra were constructed and subtracted from the observed ones in order to obtain the circumstellar component, where we have looked for evidence of accretion. Three stars exhibited evidence of accretion, HD100546, HD142666 and HD145718 and the behavior of the RACs was different in each case.

The RACs observed in HD142666 exhibited a behavior expected from an infalling gaseous structure, rich in hydrogen, that





**Fig. 11.** Comparison between our results and the results from literature for HD169142. The solid curve represents the observed spectrum, the dashed line represents the synthetic spectrum built with our parameters while the dot-dashed and dotted lines represent the synthetic spectra built with the parameters of Dunkin et al. (1997) and SIMBAD, respectively. Panel (a) shows the H $\delta$  line profile and panel (b) shows the Fe II 4957Å line.

was probably part of the inner disc of the star. There is also evidence for BACs in the circumstellar components of the first and second nights, but not in the third night. The kinematic behavior is similar to the one of RACs.

The velocity behavior of the HD145718's RACs is opposite to the one exhibited by HD142666. The velocity of the absorption feature diminishes along the observations. This behavior might be qualitatively explained by the assumption of magnetospheric accretion. However, more spectra and more detailed modelling work are needed for a quantitative explanation.

The RACs observed in HD100546 do not show any systematic behavior. More observations with a higher temporal coverage are necessary to better understand the accretion and ejection events.

Despite the different kinematic behavior of the RACs, their presence in the Balmer lines show that the accreting material in these HAEBE stars is rich in hydrogen, what discards the possibility of an origin in comet-like bodies in star-grazing orbits. However, to better understand the dynamics of the accretion process in HAEBE stars a systematic observational campaign is necessary.

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## References

- Acke B., & Waelkens C. 2004, *A&A*, 427, 1009  
 Augereau J.C., Lagrange A.M., Mouillet D., & Menard F. 1999, *A&A*, 350, 51  
 Augereau J.C., Lagrange A.M., Mouillet D., & Menard F. 2001, *A&A*, 365, 78  
 Borra E. F., Landstreet J. D., & Mestel L. 1982, *ARA&A*, 20, 191  
 Dunkin S.K., Barlow M.J., & Ryan S.G. 1997, *MNRAS*, 286, 604  
 de Winter D., van den Ancker M.E., Maira A., Thé P.S., et al. 2001, *A&A*, 380, 609  
 Finkenzeller U., & Mundt R. 1984, *A&AS*, 55, 109  
 Franco G.A.P. 1990, *A&A*, 227, 499  
 Friedemann C., Gürtler J., & Löwe M. 1996, *A&AS*, 117, 205  
 Grady C.A., Pérez M.R., Talavera A., Bjorkman K.S., et al. 1996, *A&AS*, 120, 157  
 Grady C.A., Polomski E.F., Henning Th., Stecklum B., Woodgate B.E., Telesco C.M., et al. 2001, *AJ*, 122, 3396  
 Grinin V.P., Kozlova O.V., & Natta A., et al. 2001, *A&A*, 379, 482  
 Herbig G.H. 1960, *ApJS*, 4, 337  
 Hubrig S., Yudin R.V., Schöller M., & Pogodin M.A. 2006, *A&A*, 446, 1089  
 Hu J.Y., Thé P.S., & de Winter D. 1989, *A&A*, 208, 213

- Koch R.H., Sobieski S., & Wood F.B. 1963, *Pub. Univ. of Pennsylvania, Astro. Series 9*  
 Kurtz D.W., & Müller M. 2001, *MNRAS*, 325, 1341  
 Malfait K., Bogaert E., & Waelkens C. 1998, *A&A*, 331, 211  
 Mazzitelli I. 1989, *ApJ*, 340, 249  
 Mazzitelli I., D'Antona F., & Caloi V. 1995, *A&A*, 302, 382  
 Merin B., Montesinos B., Eiros C., Solano E., Mora A., et al. 2004, *A&A*, 419, 301  
 Meeus G., Waelkens C., & Malfait K. 1998, *A&A*, 329, 131  
 Mora A., Natta A., Eiroa C., Grady C.A., de Winter D., et al. 2002, *A&A*, 393, 259  
 Mora A., Eiroa C., Natta A., Grady C.A., de Winter D., et al. 2004, *A&A*, 419, 225  
 Muzerolle J., D'Alessio P., Calvet N., & Hartmann L. 2004, *ApJ*, 617, 406  
 Natta A., Grinin V.P., & Tarnopolska L.V. 2000, *ApJ*, 542, 421  
 Oudmaijer R.D., Palacios J., Eiroa C., Davies J.K., de Winter D., et al. 2001, *A&A*, 379, 564  
 Paatz G., & Camenzind M. 1996, *A&A*, 308, 77  
 Pérez M.R., van den Ancker M.E., de Winter D., & Bopp B.W. 2004, *A&A*, 416, 647  
 Perryman M.A.C., Lindegren L., Kovalevsky J., Hog E., & Bastian U., et al. 1997, *A&A*, 323, 49  
 Racine R. 1968, *AJ*, 73, 233  
 Shu F., Najita J., Ostriker E., et al. 1994, *ApJ*, 429, 781  
 Slawson R.W., Hill R.J., & Landstreet J.D. 1992, *ApJ*, 82, 117  
 Thé P.S., de Winter D., & Pérez M.R. 1994, *A&AS*, 104, 315  
 Valenti J.A., & Piskunov N. 1996, *A&AS*, 118, 59 5  
 van den Ancker M.E., Thé P.S., Tjin A. Djie H.R.E., Catala C., de Winter D., Blondel P.F.C., & Waters L.B.F.M. 1997, *A&A*, 324, L33  
 van der Veen W.E.C.J., Waters L.B.F.M., Trams N.R., & Matthews H.E. 1994, *A&A*, 285, 551  
 Ventura P., Zeppieri A., Mazzitelli I., & D'Antona F. 1998, *A&A*, 334, 953  
 Vieira S.L.A., Pogodin M.A., & Franco G.A.P. 1999, *A&A*, 345, 559  
 Vieira S.L.A., Corradi W.J.B., Alencar S.H.P., Mendes L.T.S., Torres C.A.O., Quast G.R., Guimarães M.M., & da Silva L. 2003, *AJ*, 126, 2971  
 Wade G.A., Drouin D., Bagnulo S., Landstreet J.D., et al. 2005, *A&A*, 442, 31  
 Wolf G.W., & Kern J.T. 1983, *ApJ*, 52, 429