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# $\beta$ Pic-like circumstellar disk gas surrounding HR 10 and HD 85905

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**Abstract.** We present high spectral resolution observations of the absorption lines of Ca II and Na I associated with the circumstellar gas disk surrounding the two A-type shell stars HR 10 and HD 85905. Data taken over two four-night periods in January and November 1997 reveal substantial changes in the circumstellar absorption line profiles between successive observations of both stars. Such variable features have both blue and red-shifted velocities up to 50 km $s^{-1}$ away from the central absorbing component, and are similar to those routinely observed in the $\beta$ Pictoris system. The sporadic presence of the circumstellar absorption components observed towards both HR 10 and HD 85905 may be explained by the infalling evaporating comet model developed for the $\beta$ Pictoris system by Beust et al. (1990). We note that variable circumstellar absorption features have also been detected in rapidly rotating A-type stars, such that they may be suffering irregular mass-loss that could give rise to similar circumstellar disks and shells.

**Key words:** circumstellar matter – stars: individual: $\beta$ Pic – stars: individual: HD 85905 – stars: individual: HR 10

## 1. Introduction

The IRAS mission detected cool, dusty disks surrounding several nearby main sequence stars such as Vega, Fomalhaut and $\beta$ Pictoris (Aumann et al. 1984; Backman and Paresce 1993). Subsequent optical coronographic imaging by Smith and Terrile (1984) revealed the dust surrounding $\beta$ Pic to be an edge-on disk some 1000 AU in extent, and in order to explain the observed high value of infrared excess from $\beta$ Pic, continuous replenishment of this disk is required. This reprocessing is now thought to be linked with the evaporation/collisions of large numbers of infalling, solid bodies (i.e. comets), such that it is widely believed that we are witnessing the planetesimal clearing out stage of a planetary system (Lecavelier et al. 1996). Current theories concerning stellar formation suggest that planetary formation may be a common event, since planets are thought to be assembled from the dust grains that surround a star at the time of its birth. Clearly, if a link between circumstellar dust disks and planets can be universally demonstrated, then the frequency of occurrence of these circumstellar disk features could provide an estimate of the frequency of occurrence of planetary systems.

Although infrared dust excesses from main sequence stars are quite common (Backman and Paresce 1993), only direct imaging can unambiguously confirm the actual presence of a circumstellar dust disk. An unsuccessful optical search for $\beta$ Pic-like dust disks around 124 nearby dwarf B - M type stars was carried out using coronographic imaging techniques by Smith et al. (1992). They interpreted these null results as being due to the presence of either an unusually large amount of optically scattering material, or unfavorable orientations of the line-of-sight view factors. To date, optical imaging of circumstellar dust disks has been achieved for a very limited number of objects that include $\beta$ Pic (Smith and Terrile 1984), HH 30 (Stapelfeldt et al. 1997), several young objects in the Orion nebula (O'Dell and Wen 1994) and the recent observations of BD+31643 (Kalas and Jewitt 1997).

The $\beta$ Pic dust disk is also accompanied by a circumstellar gaseous component. This circumstellar gas, which is viewed as an 'edge-on' disk (or torus) in the $\beta$ Pic system, has been detected using high resolution absorption-line spectroscopy using both the Ca II K-line at 3933Å (Hobbs et al. 1985), and several ultraviolet resonance lines observed with IUE and HST (Kondo and Bruhweiler 1985; Lagrange et al. 1995). Strong temporal variations have been observed in these circumstellar absorption line profiles, similar to the more extreme forms of photometric, spectroscopic, and polarimetric irregular variability observed towards the possibly related Herbig Ae and Be class of stars (Grady et al. 1996; Pogodin 1997). There is now considerable evidence that the bulk of the circumstellar gas contained within the $\beta$ Pic disk lies within $\sim 1$ AU of the star (Hobbs et al. 1988; Lagrange et al. 1998), and the fact that the strongest line profile variations are mostly redshifted with respect to the stellar radial velocity strongly suggests that they are caused by solid, kilometer-sized bodies evaporating as they fall towards the star on grazing, parabolic orbits (Beust et al. 1990). More recent studies of this system by Levison et al. (1994) may require the presence of a planet-sized body within the gas disk in order to explain these observational data.

Recent ultraviolet observations of HR 10, HR 2174, 51 Oph, 2 And, and HD 100546 have revealed accreting clumps of circumstellar (disk) gas continuously falling onto these stars in a similar manner to that routinely observed in the $\beta$ Pic system (Lecavelier et al. 1997a ; Cheng et al. 1997 ; Grady et al. 1997). To more fully understand the link between this infalling gaseous material and the presence of dust disks in the role of planetary system formation, more instances of stars with associated protoplanetary gaseous disks observed at different stages in their evolutionary history are clearly required. Unfortunately, searches for other stars with variable circumstellar gas absorption similar to that exhibited by the Ca II profiles routinely observed towards $\beta$ Pic have been largely unsuccessful (Lagrange-Henri et al. 1990a ; Cheng et al. 1995 ; and Lecavelier et al. 1997b). However, tentative evidence for some circumstellar Ca II profile variability has been reported for both HR 2174 (Lagrange-Henri et al. 1991) and HR 10 (Lagrange-Henri et al. 1990b).

Our present approach in finding new stellar targets with gaseous circumstellar disks is to identify some of the key physical characteristics of the one star that has a well-observed circumstellar disk, i.e. $\beta$ Pic. Three attributes of the associated absorption and emission have been clearly identified from the many visible and infrared observations of the $\beta$ Pic system: (i) $\beta$ Pic exhibits a large infrared 'dust' excess of emission at 12, 25 and 100 $\mu$ m (Aumann et al. 1984), that has been associated with the presence of a disk of crystalline silicates similar to those found in several solar system comets (Waelkens et al. 1996). A large proportion of the Ae/A class of shell stars are, like $\beta$ Pic, anomalous infrared emitters (Jaschek et al. 1991) and many also show high levels of optical polarization (Bhatt 1996), (ii) $\beta$ Pic has an observed anomalously high ratio of the circumstellar absorption column densities for the visible lines of Ca II / Na I of $>$ 10:1, which clearly differentiates the circumstellar gas component from that of normal interstellar gas (Vidal-Madjar et al. 1986 ; Welsh et al. 1997), and (iii) Observations of the circumstellar Ca II K absorption lines towards $\beta$ Pic have revealed significant changes in these line profiles over timescales of $<$ 1 day (Lagrange-Henri et al. 1992 ; Crawford et al. 1994 ; and Welsh et al. 1997). Especially significant is the detection of varying high velocity redshifted absorption components in the circumstellar Ca II profiles that are indicative of an accretion process thought to be due to infalling evaporating comet-like bodies, suggesting that planetesimal formation in the surrounding disk is well advanced (Beust et al. 1989). With only a single observation, it can be virtually impossible to distinguish a circumstellar absorption line from an interstellar one. Thus definitive identifications can only be made by multiple observations of the same absorption line, such that variations in the line-profile would indicate a probable circumstellar origin.

Using the three aforementioned physical identifiers of the $\beta$ Pic disk system, we have begun a program of observations of potential $\beta$ Pic-like stars to search for similar temporal variations in their circumstellar Ca II absorption profiles. In this Paper we report on high resolution (4.5 km s$^{-1}$) spectral observations of the circumstellar Ca II and Na I absorption components observed over two 24 hour periods spaced 10 months apart in 1997 towards two such stars: HR 10 (A2IV, d = 160pc) and HD 85905 (A2V, d = 140pc). In addition we present two ultra-high resolution (0.3 km s$^{-1}$) Ca II spectra of HR 10 taken in November 1996 and June 1997.

Both stars show significant variations in their Ca II absorption characteristics, in a manner similar to those routinely observed in the $\beta$ Pic system. In addition we have observed weak Na I absorption towards both HR 10 and HD 85905, such that the Ca II / Na I ratio is $\sim$ 5.0. We interpret these two aspects of variable absorption as confirmation of the presence of circumstellar, possibly protoplanetary gaseous disk material (similar to that observed towards $\beta$ Pic) surrounding both stars.

## 2. Observations and data reduction

The majority of our observations were made using the fiber-fed echelle spectrograph on the 1.5m telescope at the Cerro Tololo Inter-American Observatory (CTIO) in Chile during two observing runs in January 1997 and November 1997. A log of the exact dates of each observation of the Ca II K-line at 3933 Å and the Na I doublet at 5890 Å is given in Table 1, along with relevent astronomical data for each of the two target stars, HR 10 and HD 85905, compiled using the SIMBAD data retrieval system of the Astronomical Data center in Strasbourg, France. All of the CTIO observations were taken at a resolving power of R $\sim$ 66,000 (4.5 km s$^{-1}$), and wavelength calibration of the spectra was obtained using a Th-Ar lamp comparison spectrum, which resulted in a wavelength accuracy of 0.008Å (0.6 km s$^{-1}$) for each data set. The CCD images were divided by a flat-field, and the CTIO spectra were extracted using the IRAF data reduction package as described in Welsh et al. (1997). All spectra were well-exposed with typical resultant S/N ratios in excess of 30:1.

In addition, we have obtained two spectra of the Ca II K-line towards HR 10 observed on November 30th 1996 and June 20th 1997 at a resolving power of $\sim$ 970,000 (0.3 km s$^{-1}$) using the UHRF spectrograph on the Anglo-Australian Observatory (AAO) 3.9m telescope (Diego et al. 1995). The UHRF spectra were extracted using the FIGARO data reduction routines (Shortridge 1988), and are shown in Fig. 3.

Both stars exhibited strong photospheric Ca II absorption together with circumstellar lines formed at (or near, see below) the stellar radial velocity in the center of the photospheric line cores, similar to those routinely recorded towards the star $\beta$ Pic (Lagrange-Henri et al. 1990a; Welsh et al. 1997). Two typical spectra of HR 10 for the nights of November 17th and 18th 1997 showing both the broad stellar photospheric and the central, narrow circumstellar Ca II K-lines are shown in Fig. 1. In order to obtain the normalized profiles of the circumstellar absorption lines, the effects of the broad stellar photospheric Ca II absorption were removed from both stars' spectra. Because of asymmetries in the stellar line profiles, this was accomplished using high-order polynomial fitting to establish a local continuum level. The resultant normalized circumstellar Ca II spectra for both sets of observations at CTIO are plotted in Fig. 2 for HR 10 and in Fig. 4 for HD 85905.

Weak circumstellar Na I D2 lines were also observed at CTIO on the nights of January 26th, November 19th and 20th

**Table 1.** Astronomical Data and Observation Log

| Star | V | SP | V sin i | Date Observed | Observatory | Line Observed | Equivalent Width (mÅ) |
|---|---|---|---|---|---|---|---|
| HR 10 | 6.2 | A2IV | 220 km $s^{-1}$ | 11/30/96 | AAO | CaII | 57.6±6.0 |
| | | | | 1/24/97 | CTIO | CaII | 154.0±16.0 |
| | | | | 1/25/97 | CTIO | CaII | 249.7±12.2 |
| | | | | 6/20/97 | AAO | CaII | 51.3±5.5 |
| | | | | 11/17/97 | CTIO | CaII | 61.3±6.5 |
| | | | | 11/18/97 | CTIO | CaII | 231.0±10.3 |
| | | | | 11/19/97 | CTIO | NaI | 67.2±7.0 |
| | | | | 11/20/97 | CTIO | NaI | 24.8±3.5 |
| HD 85905 | 6.2 | A2V | 245 km $s^{-1}$ | 1/24/97 | CTIO | CaII | 82.2±6.0 |
| | | | | 1/25/97 | CTIO | CaII | 141.5±12.0 |
| | | | | 1/26/97 | CTIO | NaI | 22.1±3.0 |
| | | | | 11/17/97 | CTIO | CaII | 70.2±5.9 |
| | | | | 11/19/97 | CTIO | NaI | 32.5±4.0 |

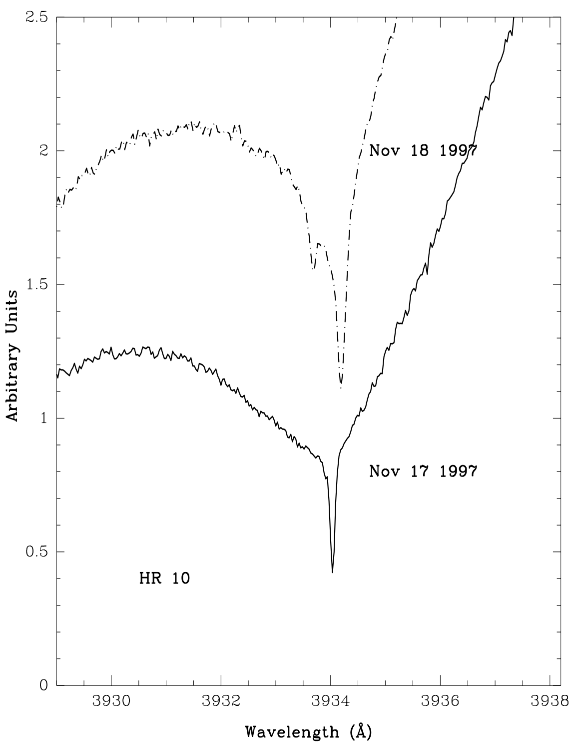


**Fig. 1.** Raw spectra of HR 10 showing both the broad photospheric Ca II lines together with the narrow circumstellar lines as observed on November 17th and November 18th 1997. Note the extra blue component in the November 18th data.

1997. These data, which are also shown in Figs. 2 and 4, were reduced in an identical manner to that of the Ca II data. The effects of telluric water vapor line absorption in the D2 spectra were removed using a technique outlined in Bertin et al. (1993).

The equivalent width of each observation of the respective Ca II and Na I absorption profiles integrated over the entire aborption line width are listed for both stars in Table 1. We have fit each of the residual intensity line profiles with one or more absorption components (i.e. 'clouds'), using a Marquardt least-squares fitting program (Vallerga et al. 1993). The best-fit values of Ca II column density, N(Ca II ), velocity dispersion ($b$) and heliocentric velocity, V, for each absorption component are listed in Table 2. We estimate typical errors of $\pm$ 0.5 km $s^{-1}$ for the derived velocity of each cloud component, and $\sim 15\%$ for the corresponding component $b$ values. The error estimates that can be associated with each the component column density values given in Table 2 were obtained by an interactive estimation procedure outlined in Crawford et al. (1997), and in most cases are typically of value $20\%$. Table 2 also lists the corresponding derived best-fit values for the absorption components of the Na I data. The best-fit theoretical absorption profiles for both stars are shown as thick lines in Figs. 2, 3 and 4.

## 3. Discussion

### *3.1. HR 10*

HR 10 (HD 256) is of spectral type A2IV/V, has a rotational velocity of 220 km $s^{-1}$ and has been listed as a shell star by Jaschek et al. (1991). It has a weak infrared excess at 12 and 25 microns which is most probably associated with a circumstellar dust disk (Cheng, Grady and Bruhweiler 1991). It has been observed previously at visible wavelengths by Lagrange-Henri et al. (1990b) who detected a narrow circumstellar component, similar to the 'stable' component of $\beta$ Pic in the core of the photospheric Ca K line. However, unlike $\beta$ Pic, it was found that this 'main' component was not stable in velocity; in observations spaced two years apart it had moved by about 8 km $s^{-1}$. In addition to this variability, Lagrange-Henri et al. also observed a variable absorption feature redshifted by 20 km $s^{-1}$ with respect to the 'main' component, which appears similar to the redshifted events frequently observed in the case of $\beta$ Pic. Grady et al. (1996) reported variable accretion phenomena in the UV lines towards this star, and similar changes in absorption arising in the circumstellar envelopes of several of the possibly related Herbig Ae/Be stars have been reported by Grinin and Tambovtseva (1995). More recently, HST GHRS ultraviolet absorption observations of HR 10 by Lecavelier et al. (1997a), have revealed the presence of Fe II ions with a definite circum-

**Table 2.** Absorption Line Fit Parameters (Component V and b in km $s^{-1}$, N in $10^{-10}$ $cm^{-2}$).

| **HR10** | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Observation | $V_1$ | $b_1$ | $N_1$ | $V_2$ | $b_2$ | $N_2$ | $V_3$ | $b_3$ | $N_3$ | $V_4$ | $b_4$ | $N_4$ | $V_5$ | $b_5$ | $N_5$ |
| 11/30/96-CaII | -14.4 | 3.7 | 7.6 | -10.4 | 2.1 | 19.4 | -7.3 | 7.7 | 36.7 | 7.4 | 3.8 | 11.9 | - | - | - |
| 1/24/97-CaII | -17.9 | 8.6 | 59.3 | -8.3 | 1.2 | 255.9 | -0.1 | 4.7 | 69.3 | 13.0 | 10.2 | 29.4 | - | - | - |
| 1/25/97-CaII | -38.2 | 10.5 | 43.5 | -11.0 | 9.5 | 118.1 | -2.0 | 8.4 | 118.5 | 17.7 | 9.6 | 77.7 | - | - | - |
| 6/20/97-CaII | -16.6 | 2.6 | 9.7 | - | - | - | 3.4 | 8.9 | 36.7 | 9.2 | 3.0 | 28.0 | 16.2 | 4.5 | 8.8 |
| 11/17/97-CaII | - | - | - | -6.6 | 5.1 | 10.2 | 3.4 | 1.9 | 127.4 | - | - | - | - | - | - |
| 11/18/97-CaII | -24.0 | 6.2 | 27.1 | -12.3 | 1.1 | 5.0 | 0.8 | 8.9 | 34.3 | 14.6 | 5.6 | 79.5 | 22.7 | 9.5 | 24.8 |
| 11/19/97-NaI | -27.2 | 8.7 | 13.3 | - | - | - | 0.0 | 9.9 | 13.5 | - | - | - | 35.9 | 7.9 | 4.1 |
| 11/20/97-NaI | - | - | - | - | - | - | 0.36 | 7.1 | 6.5 | - | - | - | 25.8 | 6.2 | 5.9 |
| **HD 85905** | | | | | | | | | | | | | | | |
| Observation | $V_1$ | $b_1$ | $N_1$ | $V_2$ | $b_2$ | $N_2$ | $V_3$ | $b_3$ | $N_3$ | $V_4$ | $b_4$ | $N_4$ | $V_5$ | $b_5$ | $N_5$ |
| 1/24/97-CaII | -15.3 | 10.8 | 43.7 | -4.7 | 4.8 | 27.1 | - | - | - | 8.5 | 5.3 | 26.0 | - | - | - |
| 1/25/97-CaII | -49.7 | 12.1 | 28.0 | -27.8 | 5.3 | 18.9 | -9.2 | 9.8 | 55.2 | 5.6 | 14.0 | 73.0 | - | - | - |
| 11/17/97-CaII | - | - | - | -10.4 | 11.4 | 10.0 | 6.2 | 8.9 | 44.8 | 9.0 | 1.1 | 25.1 | 19.8 | 6.4 | 12.4 |
| 1/26/97-NaI | -27.4 | 4.9 | 2.4 | -6.5 | 2.4 | 9.2 | - | - | - | - | - | - | - | - | - |
| 11/19/97-NaI | - | - | - | - | - | - | 9.2 | 7.6 | 16.7 | - | - | - | - | - | - |

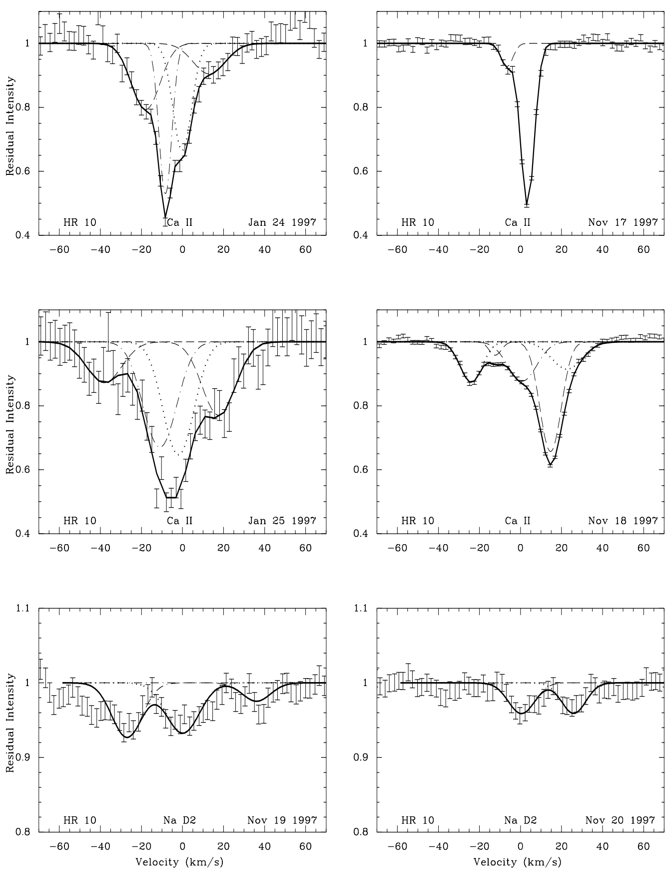


**Fig. 2.** Circumstellar Ca I I and Na I spectra of HR 10 taken at the CTIO during 1997. Dashed lines show the individual components used to fit the observed data points (shown as bars), and the resultant best-fit profile is shown as the dark, full line.

stellar origin, and also additional evidence of low velocity, but definitely clumpy, gas.

### 3.1.1. Circumstellar Ca II K-line profiles

The Ca II data shown in Figs. 2 and 3 clearly show marked absorption profile variations for both sets of observations that were each taken 24 hours apart. These changes in the circumstellar Ca II absorption profiles are as large (if not larger) as those routinely seen towards $\beta$ Pic. We also note that the changes in profile during both sets of 24 hour periods are as pronounced as the variation in circumstellar Ca II absorption seen towards HR 10 over a period of two years by Lagrange-Henri et al. (1990b).

The Ca II profile of HR 10 observed on November 17th 1997 illustrates the difficulties involved in the recognition of stars with a similar circumstellar nature to $\beta$ Pic. Note the single central component with a complete absence of any high velocity absorption components in the Ca II profile. Clearly if only this single observation had been made, no profile variation would have been assumed and thus its recognition as a potential protoplanetary gas disk would not have been made. Again, we stress the importance of making multiple observations in order to clearly identify other $\beta$ Pic-like systems.

We now draw attention to two interesting aspects of the circumstellar Ca II absorption line profile data:
(i) There are sporadic changes in *both* the red and blue wings of the main circumstellar Ca II line. In particular, the UHRF spectrum of June 20th 1997 (Fig. 3), and the CTIO spectra of January 25th and November 18th 1997 (Fig. 2), show clear evidence of discrete blue-shifted absorption events. Similar variability in the redshifted absorption components of the $\beta$ Pic system has been widely reported (Lagrange-Henri et al. 1992). However, blue-shifted absorption components are far rarer events (Beust et al. 1991 ; Crawford et al. 1998). We will return to this point in Sect. 4 below.

(ii) In the case of $\beta$ Pic the velocity of the 'main' circumstellar absorption component is stable (in over a decade of observations) and occurs at the radial velocity of the star. For HR 10 the velocity of the 'main' Ca II absorption

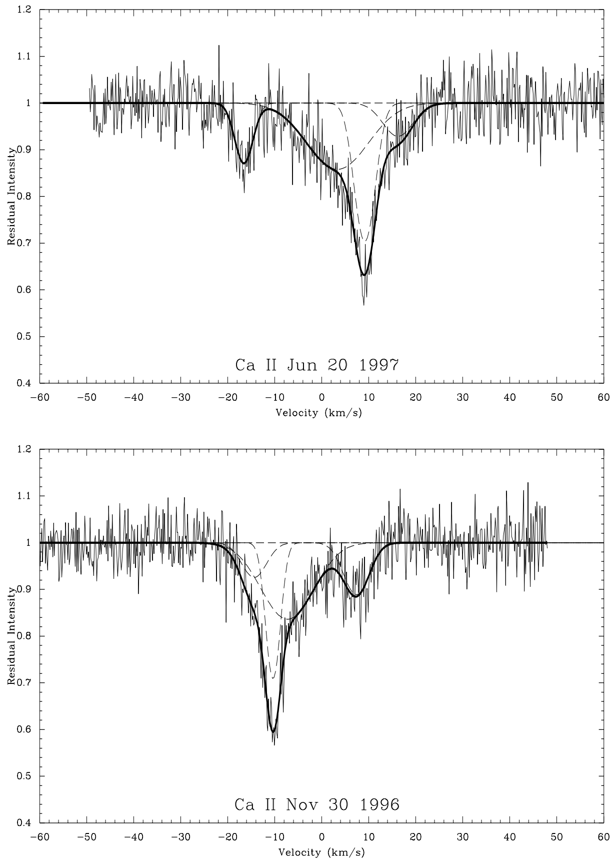


**Fig. 3.** Circumstellar Ca II spectra of HR 10 taken with the UHRF at the AAO on November 30th 1996 and June 20th 1997. Dashed lines show the individual components used to fit the observed data, and the resultant best-fit profile is shown as the dark, full line.

component is seen to change in velocity by up to ± 10 km s $^{-1}$ between successive observations (see Fig. 2). Clearly for HR 10 this 'main' component is difficult to recognize due to the complex and changing nature of the circumstellar Ca II profiles, and in this Paper we define the 'main' HR 10 component as that with the largest absorption depth on a given date of observation. As noted above, the change in velocity of the main absorption component was first observed by Lagrange-Henri et al. (1990b), who suggested that it might be due to a variable stellar radial velocity. We have checked this possibility by measuring the radial velocity of the stellar H$\beta$ line ($V_r$ = +3 km s$^{-1}$), which we find to be constant (within 1 km s$^{-1}$) between the two nights' observations. We conclude, therefore, that the changing velocity of the 'main' component is *not* due to a variable stellar velocity (i.e. the star is not a previously unsuspected spectroscopic binary), but arises due to changes within the circumstellar environment. Thus, although the 'main' circumstellar component towards HR 10 looks superficially similar to that of $\beta$ Pic, the fact that the former moves in velocity while the latter does not, may indicate that they are caused by different mechanisms within the disk.

### 3.1.2. Circumstellar Na I D-line profiles

Fig. 2 also shows the Na I D2-line profiles observed on the nights of November 19th and 20th 1997. Although the Na I D2-line absorption is weak, it is clear from the data set that a similar pattern of modulation in the velocity of the 2-component circumstellar Na I line is occuring. Over the 24-hour period between observations the circumstellar D2 profile appears to shift by $\sim$ 20 km s$^{-1}$, consistent with the observed magnitude of the velocity shift of the circumstellar Ca II line. In addition to the shift in velocity of the D2 line we also note a 50 % reduction in the level of Na I absorption over the 24 hour period. Although small changes in the level of circumstellar Na I absorption have been observed previously towards $\beta$ Pic over a 24 hour period (Welsh et al. 1997), the large variations in both velocity and column density observed for the D2 line of HR 10 are, to our knowledge, unprecedented. We note that we also observed similar variations in the instrinsically weaker Na I D1 line profiles for HR 10.

Inspection of the D2 line data also indicates the possible presence of weaker high velocity components that may also vary between observations. However, due to the low signal-to-noise for these weak lines and the possible contamination of the data by telluric water vapor lines that may have not been fully removed, we cannot attribute a circumstellar nature to them with confidence.

### 3.1.3. The Ca II to Na I ratio

Hobbs et al. (1985) first noted an anomalous column density ratio of N(Ca II ) / N(Na I ) > 10 for the circumstellar gas disk surrounding $\beta$ Pic, and a similarly high ratio was inferred for observations of HR 10 by Lagrange-Henri et al. (1992). Unfortunately our present observations of Ca II and Na I are not contemporaneous, and since the circumstellar components change their velocity and strength over short timescales it is difficult to associate the absorption from each Ca II component with that from a corresponding Na I velocity component (if indeed such a correspondence is even valid, given that for $\beta$ Pic neutral sodium is probably produced in a more extended zone, Vidal-Madjar 1986). However, if we take the ratio of the total column density of circumstellar Ca II (as measured on November 18th) and compare it with that of the total column density of Na I (as measured on November 19th), we obtain a N(Ca II ) / (N(NaI ) ratio of 5:1. This ratio value (which we deem as a lower limit for each circumstellar component) is normally only observed in either high velocity interstellar gas clouds (Siluk and Silk 1974), or the warm intercloud regions of the ISM. Although this ratio is much smaller than that found for circumstellar disk gas found in the $\beta$ Pic system, it is still consistent with a circumstellar origin for the observed HR 10 absorption.

### 3.1.4. The line widths

It is apparent from Figs. 2 and 3 that a great deal of variation occurs in the line widths of the circumstellar absorption components; narrow absorption components observed on one night appear to change into broader components 24 hours later. This must be due either to changes in the physical conditions (i.e. temperature and turbulence) within each component, or to the appearance and disappearance of discrete, but spectrally unresolved, sub-components, as might be expected on the basis of the recent comet model of Beust et al. (1998).

Indeed, the observed line profiles are perhaps suggestive of the presence of discrete, but variable, components in the blue and red wings of a 'central' narrow component which remains fairly constant in strength and width, even though it moves in velocity. For example, the profile obtained on January 24th 1997 would resemble the simple profile of November 17th 1997 if the neighboring, partially resolved, components (i.e. those at -17.9, -0.1 and +13.0 km $s^{-1}$; Table 2) were absent. It would also resemble the broad component of November 18th if additional components were present but with velocities closer to the central component, causing them to blend together. Further evidence for the presence of variable structure in the wings of a stable component, which would cause it to appear broader if observed at lower resolution, comes from our very high resolution UHRF data (Fig. 3). The velocity dispersion of the narrow component which, despite its variable heliocentric velocity seems always to be present, is fairly constant with $b \sim 2.0 \pm 1.0$ km $s^{-1}$ (this is similar to the values obtained for the central stable component observed towards $\beta$ Pic; Beust et al. 1998), although most of the neighboring components are significantly broader (the average $b$ value for the Ca II line components is 7 km $s^{-1}$).

For Ca ions, the velocity dispersion parameter, $b$, is related to the kinetic temperature, $T_k$, and the line-of-sight rms turbulent velocity, $v_t$, by

$$b = \sqrt{0.413\Big(\frac{T_k}{1000\mathrm{K}}\Big) + 2v_t^2} \qquad \mathrm{kms}^{-1}, \qquad (1)$$

and this equation may be used to place limits on the temperature and turbulence of the circumstellar medium. For example, by assuming $v_t = 0$ we can obtain rigorous upper limits to the kinetic temperature. The mean Ca II velocity dispersion of $b \approx 7$ $\mathrm{kms}^{-1}$ corresponds to a kinetic temperature upper limit (obtained by assuming $v_t = 0$) of over $10^5$K. However, it is most unlikely that the kinetic temperature is anything like this high (as it would result in the collisional ionisation of $Ca^+$ to $Ca^{++}$), so either significant turbulence ($v_t \approx 5$ $\mathrm{kms}^{-1}$) is present in the circumstellar gas, or some other process is broadening the line profiles.

The various mechanisms responsible for broadening absorption line profiles in circumstellar disks are discussed in Sect. 3.1 of Beust et al. (1998). In addition to the thermal and turbulent contributions, for gas in a Keplerian orbit it is necessary to consider the radial component of the orbital velocity projected onto the finite angular size of the stellar photosphere (Eq. 1 of Beust et al. 1998). For material close to the star, the latter effect can dominate; for example, at a distance of 0.15 AU from an A2 star the projected orbital velocity will produce a $b$ value of about 10 km $s^{-1}$. A $b$ value of 2 km $s^{-1}$, as obtained for the central component observed towards HR 10, would correspond to an orbital distance of 0.45 AU, although this must be a lower limit as thermal and turbulent effects would broaden the line further. We note that Lecavelier et al. (1997a) obtained similar distance limits for HR 10 by applying this argument to their UV Fe II lines observed with HST. Moreover, gaseous clumps within this material would be expected to produce line profile variations as they move in front of the star. We return to this point in Sect. 4 below.

### *3.2. HD 85905*

This star, of spectral type A2V and of rotation velocity 245 km $s^{-1}$, is listed as a shell star (Jaschek and Egret 1982) with a level of polarization consistent with surrounding circumstellar dust material (Bhatt 1996). A single observation of HD 85905 in May 1987 by Lagrange-Henri et al. (1990a) revealed absorption centered on the bottom of the photospheric Ca II line, but a circumstellar origin could not be attributed due to (a) no indication of variability in the Ca II K-line from the single observation, (b) the lack of any observed high velocity Ca II absorption components, and (c) the unavailability of associated circumstellar Na I observations.

#### 3.2.1. Circumstellar Ca II K-line profiles

Our observations of the circumstellar Ca II line over the 24 hour period of January 16th -17th 1997 shown in Fig. 4 clearly show a similar pattern of absorption profile variability to that discussed above for HR 10. There are distinct changes in *both* the red and blue absorption wings of the circumstellar line, similar in magnitude to those observed towards HR 10. The sole observation of Ca II on November 17th 1997 shows a far simpler absorption profile indicative of a lower level of circumstellar activity, which is very similar to the Ca II profile obtained for HD 85905 by Lagrange-Henri et al. (1990a) in May 1987. Again we emphasize the need for multiple absorption observations in order to establish any system's potential $\beta$ Pic-like nature.

Due to the complexity of the Ca II profiles observed during January 1997, it is difficult to recognize a stable, central component. However, if we assume that the main absorbing component is that observed at V = $\sim$ 7 km $s^{-1}$ on November 17th, then it seems very likely that this central circumstellar component also exhibits velocity modulation effects similar to those found above for HR 10 (which may be due to a variable stellar radial velocity).

#### 3.2.2. Circumstellar Na I D-line profiles

Fig. 4 shows two Na I D2-line absorption profiles taken on January 26th and November 19th 1997. There is a 50% increase in the level of absorption between the two observations. These Na I profiles best show the velocity shift of the main absorption component from V = -6.5 km $s^{-1}$ to V = +9.2 km $s^{-1}$. We also note the transitory appearance of a blue-shifted component at V= -27.4 km $s^{-1}$ in the January 26th data.

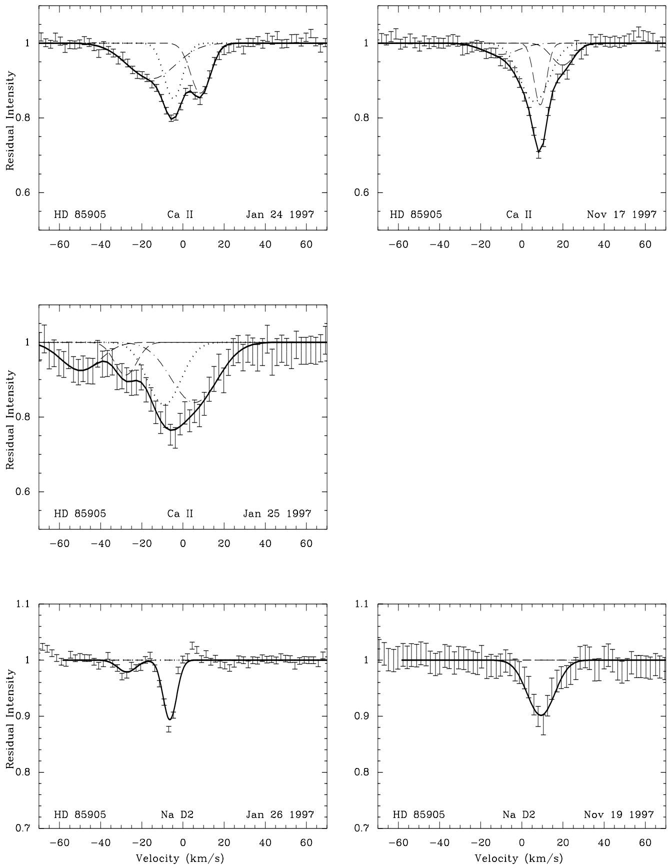


**Fig. 4.** Circumstellar Ca II and Na I spectra of HD 85905 taken at the CTIO during 1997. Dashed lines show the individual components used to fit the observed data points (shown as bars), and the resultant best-fit profile is shown as the dark, full line.

### 3.2.3. The Ca II to Na I ratio

If we assume that the absorption components centered at V $\sim$ + 7 km s$^{-1}$ in both the Ca II data of November 17th and the Na I data of November 19th are formed in a similar circumstellar region, then the N(Ca II ) / N(Na I ) ratio is 4:1. Again, this ratio is small compared to that found for disk gas in the $\beta$ Pic system, but it is very similar to that found for the HR 10 circumstellar system.

### 3.2.4. Line widths

The average $b$ value for all eleven Ca II components observed towards HD 85905 is 7.8 km s$^{-1}$, resulting in a kinetic temperature upper limit of T$_k <$ 148,000K (assuming zero turbulence). The average $b$ value for the Na I components is 5.0 km s$^{-1}$, which results in a temperature upper limit of T$_k <$ 45,500K. As for HR 10, these very high temperature upper limits imply that some other line-broadening mechanism is present, which is probably unresolved velocity structure and/or the projection effects of orbiting circumstellar gas.

## 4. Origin of the variation in circumstellar absorption

Our data clearly show a high level of variability in the circumstellar absorption characteristics of both HR 10 and HD 85905. Similar variability of circumstellar absorption components have been routinely observed in the $\beta$ Pic system for over a decade, and are well explained by the Falling-Evaporating-Bodies (FEB) scenario in which gas from kilometer-sized bodies (such as comets) is vaporized in the vicinity of the star (Beust et al. 1990). These bodies are assumed to move on parabolic orbits with a close perihelia ($\sim$ 10 stellar radii), and evaporate when grazing the star. In the case of $\beta$ Pic, the transient events are mostly red-shifted, which requires a specific direction of the axis of the parabolic orbit of the FEBs. In the cases of both HR 10 and HD 85905 we observe both red and blue shifted absorption components, which may indicate that whatever mechanism aligns the orbits in the case of $\beta$ Pic (e.g. planetary resonances; Beust et al. 1996), it is not operating for these two stars. We note that, in the absence of an alignment mechanism, the FEB model actually predicts equal numbers of red and blue-shifted events (e.g. Crawford et al. 1998). Thus, the strong blue-shifted events observed towards HR 10 on June 20th and Nov 18th 1997 are fully consistent with the FEB model.

We have found clear evidence for discrete, but variable, absorption events in both the red and blue wings of the 'central' circumstellar absorption component towards each star. It is interesting to note that UHRF observations of $\beta$ Pic have recently revealed similar variable structure in the wings of the stable circumstellar component (Beust et al. 1998), where they have been interpreted as being due to cometary-type objects crossing the line of sight at greater distances from the star than those responsible for the higher velocity events. As noted in Sect. 3.1, it is also possible that orbiting clumps of gas within the disk could give rise to these variable components, as recently suggested by Kholtygin et al. (1997) in the context of Herbig AeBe stars. However, we note that to account for the observed velocity variability ($\sim \pm 10$ km s$^{-1}$) they would have to be very close to the star ($< 0.13$ AU), unless their orbits were highly elliptical.

Given the evidence for circumstellar dust around these two stars (from the infra-red excesses), the FEB model is certainly a plausible explanation for the observed spectral variability. However, there are two caveats: (1) the FEB model has never satisfactorily explained the 'stable' absorption component in the $\beta$ Pic system (see Lagrange et al. 1998 for a recent discussion); and (2) the variable velocity of the 'central' component in both HR 10 and HD 85905 may indicate that it is formed by a different mechanism from that operating in the $\beta$ Pic system. Until these outstanding questions can be answerd satisfactorily, some doubt must remain as to how close an analogue HR 10 and HD 85905 are to the $\beta$ Pic system.

Recently, the whole question of the origin of circumstellar gas around main-sequence A stars has been reopened by Abt et al. (1997), who have detected circumstellar Ti II lines towards a number of rapidly rotating ($v \sin i \geq 200$ km s$^{-1}$) A-type stars. These observations led them to suggest that all A-type stars rotating near their limits may suffer irregular mass loss

**Table 3.** Observations of other Ae-type stars

| Star | V | Sp | V sin i (km $s^{-1}$) | Observation Date | Comments |
|---|---|---|---|---|---|
| HD 195324 | 5.9 | A1e | 15 | 8/15/97 | no C/S line present |
| HD 223884 | 6.2 | A5Ve | 210 | 7/23/97 | C/S CaII line present |
| HD 15253 | 6.5 | A2e | 160 | 8/27/96 | no C/S line present |
| HD 39182 | 6.4 | A2Vpec | 220 | 8/27/96 | C/S CaII + IS line present |
| HD 148283 | 5.5 | A5V | 260 | 8/27/96 | C/S CaII line present |
| HD 109573 | 5.8 | A0Ve | N/A | 1/24/97 | weak C/S line present |
| HD 223385 | 5.4 | A3Ie | 30 | 8/15/97 | no C/S line present |

giving rise to circumstellar disks or shells. We also note that there is a growing realization that at least the early A stars can also lose mass through radiatively driven winds (Babel 1995). Clearly, if either of these processes were responsible for the circumstellar lines towards stars such as $\beta$ Pic and HR 10, then there may be no need to invoke the evaporation of comet-like objects as a source of this circumstellar gas. On the other hand, we note that the detection of circumstellar CO towards $\beta$ Pic (Vidal-Madjar et al. 1994), does strongly suggest a cometary contribution. However, we note that CO gas is very cold ($\sim$ 20K) and should be formed at far larger distances from the central star than the circumstellar Ca II Thus, its origin may not be directly linked with the FEB's. It would therefore be of great interest to determine if CO is also present in the circumstellar environments of HR 10 and HD 85905.

## 5. Observations of other Ae-type stars

In addition to HR 10 and HD 85905, we have also performed Ca II K-line observations of the 7 stars listed in Table 3. Some are listed as Ae shell stars and others are early-type anomalous infrared emitters of peculiar spectral class. In only 3 of these stars do we detect a relatively strong and narrow, central circumstellar absorption centered at the bottom of the stellar photospheric Ca II K-line, i.e. HD 223884, HD 39182, HD 148283. These stars were also identified by Lagrange-Henri et al. (1990a) as possessing deep (circumstellar) absorption within the the broad photospheric stellar line. All three stars were observed by us at least twice over a period of 24 hours, but their circumstellar profiles were unchanged and showed no evidence of high velocity absorption components similar to those seen for HR 10, HD 85905 and $\beta$ Pic.

Recent high resolution infrared images of the star HD 109573 (HR 4796) show compelling evidence for an associated (proto)planetary dust disk (Koerner et al. 1998) Our present observations show evidence for a weak circumstellar gaseous disk around this star. However, we found no evidence for temporal changes in the Ca II circumstellar profile over a 24 hour period. Thus, we are presently unable to confirm the presence of on-going planetesimal activity in this system similar to that observed towards HR 10 and HD 85905.

No circumstellar absorption features were found towards any of the remaining 3 stars in Table 3. We note that all of these stars have rotational velocity values $<$ 160 km $s^{-1}$, which is consistent with the findings of Abt et al. (1997) in which only A-type stars that are rotating near their limits (i.e. $>$ 200 km $s^{-1}$) have shells or disks.

## 6. Conclusion

We have observed highly variable absorption associated with the circumstellar lines of Ca II and Na I seen towards the two A-type stars HR 10 and HD 85905. Such variable features have both blue and redshifted velocities of up to 50 km $s^{-1}$ away from a central absorbing component, and are similar to those routinely observed in the $\beta$ Pic system. The Ca II to Na I column density ratio for the circumstellar gas components towards both stars ($\sim$ 5:1) is somewhat lower than that found in the $\beta$ Pic system, but still significantly larger than normal interstellar values.

The sporadic presence of both red and blue shifted absorption components in the circumstellar spectra of both HR 10 and HD 85905 may plausibly be explained by the infalling cometary evaporation model developed for $\beta$ Pictoris. In particular, the discrete blue-shifted Ca II absorptions observed on June 20th and November 18th 1997 are consistent with this model for appropriate choices of the longitude of periastron of the orbits (e.g Crawford et al. 1998).

However, additional work (such as long-term monitoring of both the circumstellar and stellar lines) will be required to explain the variable radial velocity of the 'main' circumstellar components observed towards HR 10 and HD 85905. In addition, further work is required to clarify the relationship, if any, between the circumstellar gas around rapidly rotating A-stars detected Abt et al. (1997) and the $\beta$ Pic phenomenon. Only when these issues have been satisfactorily addressed will we be certain that the same processes responsible for the variable circumstellar absorption observed towards $\beta$ Pic also operate in these two newly discovered circumstellar systems.

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