Astron. Astrophys. 321, 888–890 (1997)

ASTRONOMY
AND
ASTROPHYSICS

Circumstellar disk variations around β Pictoris

B.Y. Welsh[1], **N. Craig**[2], **S. Jelinsky**[1], **and T. Sasseen**[1]

[1] Experimental Astrophysics Group, Space Sciences Laboratory, University of California, Berkeley, CA 94720-7450, USA
[2] Center for EUV Astrophysics, Space Sciences Laboratory, University of California, Berkeley, CA 94720-5030, USA

Received 10 September 1996 / Accepted 4 November 1996

Abstract. We present high resolution spectral observations of the absorption lines of Ca II and Na I associated with the circumstellar disk surrounding the star β Pictoris. The observations were taken over a four night period in January 1996 and reveal substantial profile variability between successive nights. High velocity absorption features at velocities of +58 km s^{-1} were observed in the Ca II data, but were not present in the Na I profiles. An unusually high Ca II: Na I ratio of $\sim$ 150:1 was found for the central, stable V = +22 km s^{-1} component.

Key words: stars: circumstellar matter – stars: β Pic

1. Introduction

It is now well established that the nearby (d = 16 pc) star β Pictoris (A5Ve) possesses a circumstellar disk which we observe from an "edge-on" perspective (Smith & Terrile 1984). Although optical images have provided limits of $\sim$ 400 AU to the spatial extent of the dust in this disk (Paresce & Burrows 1987), the gaseous material very close to the star (i.e., $<$ 1 AU) is best observed using high resolution absorption spectroscopy (Hobbs et al. 1985, Vidal-Madjar et al. 1986). Such observations have revealed complex time variability of the circumstellar absorption, particularly in the lines of Ca II and Mg II (Lagrange, Ferlet & Vidal-Madjar 1987, Ferlet, Hobbs & Vidal-Madjar 1987). A stable gaseous absorption component centered at $V_{\rm helio}$ = +22 km s^{-1} is often augmented by variable, red-shifted absorption features. This complex absorption variability is thought to be due to an accretion process caused by infalling evaporating bodies (such as comets), suggesting that planetesimal formation in the disk is well advanced (Lagrange-Henri, Vidal-Madjar & Ferlet 1988).

The vast majority of visible interstellar absorption observations towards β Pic have been carried out using the Ca II K-line at 3933 Å (Lagrange-Henri et al. 1992, Crawford et al. 1994). Many of these observations have revealed the presence of red-shifted components, which can vary in strength over time-scales of less than one day, that accompany the strong stable absorption component centered at the stellar rotational velocity of β Pic ($V_{\rm helio}$ = +22 km s^{-1}). Observations of the Na I D-lines around 5890 Å toward β Pic are far less common, mainly due to the observed weakness of the D-lines ($\sim$ 10 mÅ) and to the troublesome effects of telluric absorption features that complicate interpretation of the data. However, the Na I data of Hobbs et al. (1985) and Vidal-Madjar et al. (1986) showed pronounced circumstellar absorption centered at + 21 km s^{-1} which varied in strength by $\sim$ 25% over a 5 month period. Two major findings from these observations have been the inability to detect any red-shifted Na I absorption components, and the determination of an anomalously high Ca II: Na I ratio of $\sim$ 40:1 for the main absorbing component. Such a high ratio is normally only found in high velocity interstellar gas clouds, and Lagrange-Henri et al. (1990) have used this density ratio as a possible discriminator in finding circumstellar disk gas around other β Pic-like stars.

Since the circumstellar absorption features observed towards β Pic are highly variable and change almost on a daily basis, it is clearly of great interest to maintain a regular record of observations at as many epochs as possible for future comparative purposes. Hence, in this Paper we report the state of the gaseous circumstellar Ca II -K and Na I -D line components as observed over a 4-day period from January 26th–29th 1996.

2. Observations and data reduction

The observations were made using the fiber-fed echelle spectrograph on the 1.5m telescope at the Cerro Tololo Inter-American Observatory in Chile. Observations of the circumstellar Ca II K-line at 3933 Å were made on the nights of January 27th and 28th 1996, and observations of the Na I doublet around 5890 Å were made on the nights of January 29th and 30th. The data, taken at a resolving power of R $\sim$ 66,000 (4.5 km s^{-1}), were reduced in an identical manner to that described in Welsh et al. (1994). Wavelength calibration of the spectra was obtained using a Th-Ar lamp comparison spectrum, which resulted in a wavelength accuracy of 0.008 Å. All four spectra were well-exposed with typical resultant S/N ratios in excess of 60:1.

Equivalent widths of the Ca II and Na I absorption lines and their associated measurement errors are listed in Table 1. The residual intensity profiles for all 4 nights' observations are

Send offprint requests to: bwelsh@ssl.berkeley.edu

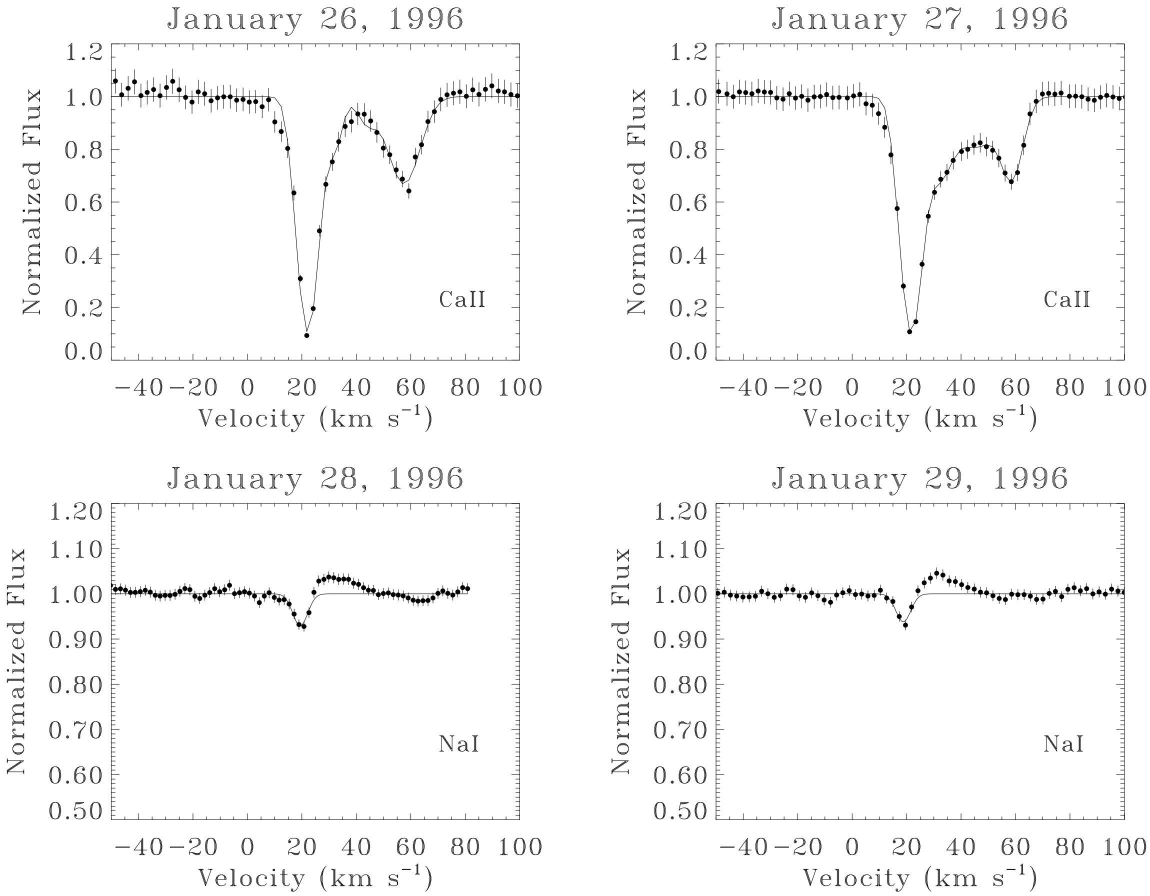

Fig. 1a–d. Observed and best-fit residual intensity plots of the Ca II and Na I circumstellar absorption lines recorded over the period January 26th–29th, 1996.

shown in Figs. 1a-d. These profiles were fit simultaneously with cloud absorption components, each described by a Gaussian velocity dispersion parameter, *b*, a heliocentric velocity, *V*, and a column density, *N* (see Vallerga et al. 1993). The derived best-fit values of these fit parameters are also listed in Table 1. Typically, such values have an associated statistical error of $\sim$ 10%.

3. Discussion and conclusion

3.1. Calcium profiles

Fig. 1a and b clearly show the well-known "stable" component at V = +22 km s^{-1} together with a well-defined red-shifted absorption feature at V = +58 km s^{-1}. Components with this magnitude of red-shifted velocity have been observed by several authors, the most recent observation being Crawford et al. (1994). A comparison of both Ca II profiles shows a significant change in the total circumstellar absorption during the 24 hour period between observations, with the total equivalent width increasing by 15% from 212.4 mÅ to 244.6 mÅ. An overlay of both nights' profiles suggests that the central absorbing component probably did not change its absorption characteristics between observations. Our profile fits indicate that the observed increase in overall absorption was due to a change in the strength of absorbing clouds with velocities lying between +30 and +50 km s^{-1}. Due to the limited spectral resolution of our observations some of this extra absorption is blended within the red wing of the central component of the Jan-27th data, and is manifested in our line profile fitting as an increase in both the column densities of the V = +32 and + 45 km s^{-1} components as well as an increase in the *b* value and column density of the central V = +22 km s^{-1} component.

3.2. Sodium profiles

Fig. 1c and 1d again clearly show the "stable" central component, but at a slightly different velocity of V $\sim$ 19.0 km s^{-1}. This small velocity difference between the central Ca II and Na I components of $\sim$ 3 km s^{-1} is real, and has been reported previously by Vidal-Madjar et al. (1986). If we assume an average Ca II column density for the first two nights' observations of the V = +22 km s^{-1} component of N(Ca II) = 7.66 $\times$ 10^{12} cm^{-2}, and a similarly averaged column density for the last two nights' observations of the Na I line of N(Na I) = 5.15 $\times$ 10^{10} cm^{-2}, then we derive a Ca II : Na I column density ratio of 148.7 for the central absorption component. This value is a factor 4 larger than that found for observations made in 1984/85

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

Observation	Total EW	Component 1			Component 2			Component 3			Component 4		
	(mÅ)	V	b	N	V	b	N	V	b	N	V	b	N
Jan 26 (Ca II)	212.4 ± 4.0	+22.2	2.7	684.6	+32.0	0.66	37.6	+43.9	2.9	13.3	+57.4	6.9	85.4
Jan 27 (Ca II)	244.6 ±5.0	+21.8	2.9	846.4	+32.1	4.8	55.1	+45.4	9.7	58.7	+58.7	4.0	53.7
Jan 28 (Na I)	9.3 ±0.8	+19.3	0.39	5.4	—	—	—	—	—	—	—	—	—
Jan 29 (Na I)	7.6 ±0.8	+18.7	0.29	4.9	—	—	—	—	—	—	—	—	—

by Vidal-Madjar et al. (1986). As stated previously, such high values of this ratio are abnormal for galactic interstellar gas in which a Ca II : Na I ratio of around unity is generally observed. The presently derived high ratio of ∼ 150:1 is unusual even for the very high velocity interstellar gas clouds typically observed towards supernovae remnants (Danks and Sembach 1995). This leads us to support the findings of Vidal-Madjar et al. (1986) in which the central Ca II absorbing component is in fact comprised of at least two weaker components (unresolved in the saturated Ca II line by our present observations), one being centered at the Na I velocity (V = +19.0 km s^{-1}) and the other at the main Ca II absorbing velocity of +22 km s^{-1}.

The broad "emission-feature" (EW ∼ 11 mÅ) observed in both nights' Na I D2 profiles is most probably due to incomplete removal of a blend of the many telluric water-vapor lines which pervade this region of the spectrum, and ultimately determines the magnitude of fluctuations in the continuum level of the Na I spectra. The template star used in the division process to remove such features was β CMa, which has known negligible interstellar sodium absorption (Welsh 1991, Ferlet et al. 1985). However, a similar emission feature was observed accompanying the weaker D1 lines on both nights which would imply an interstellar origin towards β CMa (which we deem unlikely due to the previous null measurements). We note that red-shifted emission features in the Na I spectra of β Pic have been reported elsewhere (see Fig. 1c of Vidal-Madjar et al. 1986), and were similarly discounted as being artifacts of the spectral division process. Clearly further Na I observations are required to determine the reality of such emission features which are similar to those observed in the Na I spectra of Herbig AeBe stars (Grinin et al. 1994).

The equivalent width of the Na I D2 line decreased by 20% over the 24 hour period between observations, which is the inverse of the Ca II K-line behavior for the preceding two nights. A similar reduction in absorption between nights was also observed in the Na I D1 lines (not shown). We also note that weak red-shifted absorption features are present in the Na I spectra around V = +60 km s^{-1}. However, due to the uncertainty in the telluric line removal process and the associated continuum noise fluctuations, we cannot assign a circumstellar origin to them with any confidence.

A comparison of the b values obtained from the Ca II line-fitting results indicates (in the absence of turbulence) that the kinetic temperature of the gas in the V = +58 km s^{-1} components (∼ 15,000K) is much higher than that of the central component (∼ 3800K). Beust et al. (1991) have argued that the high velocity red-shifted components are formed closer to the central star, where radiation pressure on the Ca II ions is larger and is probably responsible for the observed higher velocity dispersion of the ions. Such a scenario is also consistent with the observed absence of high velocity Na I features which would be more easily ionized in these inner disk regions.

In conclusion, it is clear from the present observations that further, more frequent observations of the Na I D-lines are required for β Pic. Although much information on the velocity behavior of this system can be gained from the well-observed Ca II K-lines, simultaneous observations of both Na I and Ca II lines are required to obtain more meaningful physical insights.

References

Beust, H., Vidal-Madjar, A., Lagrange-Henri, A.M., Ferlet, R., 1991, A&A 241, 488

Crawford, I., Spyromilio, J., Barlow, M.J., Diego, F. Lagrange, A.M., 1994, MNRAS 266, L65

Danks, A., Sembach, K., 1995, AJ 109, 2627

Ferlet, R., Vidal-Madjar, A., Gry, C., 1985, ApJ 298, 838

Ferlet, R., Hobbs L.M., Vidal-Madjar, A., 1987, A&A 185, 267

Grinnin, V.P., The, P.S., de Winter, D., Giampapa, M., Rostopchina, A.N., Tambovtseva, L.V., van den Ancker, M.E., 1994, A&A 292, 165

Hobb, L.M., Vidal-Madjar, A., Ferlet, R., Albert, C.E., Gry, C., 1985, ApJ 293, L29

Lagrange, A.M., Ferlet, R., Vidal-Madjar, A., 1987, A&A 173, 289

Lagrange-Henri, A.M., Vidal-Madjar, A., Ferlet, R., 1988, A&A 190, 275

Lagrange-Henri, A.M., Ferlet, R., Vidal-Madjar, A., Beus, H., Gry, C., Lallement, R., 1990, A&AS 85, 1089

Lagrange-Henri, A.M., Gosset, E., Beust, H., Ferlet, R., Vidal-Madjar, A., 1992, A&A 264, 637

Paresce, F., Burrow, C., 1987, ApJ 319, L23

Smith, B.A., Terrile, R.J., 1984, Sci 226, 1421

Vallerga, J.V., Vedder, P.W., Craig, N., Welsh, B.Y., 1993, ApJ 411, 729

Vidal-Madjar, A., Hobbs, L.M., Ferlet, R., Gry, C., Albert, C.E., 1986, A&A 167, 325

Welsh, B.Y., 1991, ApJ 373, 556

Welsh, B.Y., Craig, N., Vedder, P.W., Vallerga, J.V., 1994, ApJ 437, 638

This article was processed by the author using Springer-Verlag LaTeX A&A style file *L-AA* version 3.