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Detection of a strong transient blueshifted absorption component in the β Pictoris disc

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ABSTRACT

We present high-resolution spectra (1.0 km s^{-1} FWHM) of the circumstellar Ca K line towards β Pictoris obtained on 1997 June 19 and 20. On the former date a strong absorption component was found at a heliocentric velocity of $v_{\mathrm{helio}} = +8$ km s^{-1}, that is *blueshifted* by 14 km s^{-1} with respect to the main, 'stable', circumstellar component at $v_{\mathrm{helio}} = +22$ km s^{-1}. To our knowledge, this is the first detection of a blueshifted Ca II component with a strength comparable to the more frequently observed redshifted events. On the following night a blueshifted component was still present, but its strength had decreased significantly; in addition, a strong redshifted component had appeared at $v_{\mathrm{helio}} = +54$ km s^{-1} which was absent on the previous night. The implications of these observations for the evaporating 'comet' model of spectral variations in the β Pictoris disc are discussed.

Key words: line: profiles – circumstellar matter – stars: individual: β Pic.

1 INTRODUCTION

The A5V star β Pictoris was shown to be surrounded by a circumstellar disc by optical coronographic imaging (Smith & Terrile 1984), following the earlier discovery of an infrared excess by the *IRAS* survey (Aumann 1984). The edge-on orientation of the disc means that it can be studied by absorption-line spectroscopy against the stellar photosphere, and the gaseous component was first studied in this way by Hobbs et al. (1985). Subsequent observations (e.g. Ferlet, Hobbs & Vidal-Madjar 1987; Lagrange-Henri et al. 1992; Lagrange et al. 1996) have revealed strong temporal variations in the red wing of the circumstellar Ca K line, and these are now generally interpreted as being due to the evaporation of solid, km-sized bodies falling towards the star (e.g. Lagrange-Henri, Vidal-Madjar & Ferlet 1988; Beust 1994; Beust et al. 1990, 1996).

In an earlier paper (Crawford et al. 1994) we reported very-high-resolution observations ($R \equiv \lambda/\Delta\lambda \gtrsim 9 \times 10^5$) of the circumstellar Ca K line towards β Pic, obtained in 1993 using the Ultra-High-Resolution Facility (UHRF) at the Anglo-Australian Telescope. In common with earlier studies, these observations found significant temporal variations in the circumstellar line profiles (cf. fig. 1 of Crawford et al. 1994). Given the importance of this object for theories of planetary system formation, we here present additional observations obtained with the UHRF in 1997 June, at the end of two nights devoted to another project. These new observations are of interest mainly because of the detection of a strong absorption component *blueshifted* with respect to the main, 'stable', circumstellar component, which occurs at the stellar radial velocity. Although two weak blueshifted components have been reported previously (Lagrange-Henri et al. 1992), and earlier UHRF observations have revealed temporal changes in the blue wing of the stable component (Crawford et al. 1994; Beust et al., in preparation), to our knowledge this is the first detection of a blueshifted absorption component of comparable strength to the more commonly observed redshifted events.

2 OBSERVATIONS

UHRF observations were obtained of the Ca II K line region of β Pic on 1997 June 19 and 20. On both dates a single 1200-s exposure was obtained, beginning at 20:00 UT (i.e. as soon as the object had risen above the telescope zenith distance limit of 65°). The detector was the AAO 1024×1024 Tektronix CCD (24-μm pixels) and the dispersion was 0.086 Å mm^{-1}. The spectrograph has been described in detail by Diego et al. (1995), and for these observations was used in conjunction with an image slicer (Diego 1993). The CCD output was binned by a factor of 8 perpendicular to the dispersion direction in order to reduce the readout noise associated with extracting the very broad spectrum produced by the image slicer. The resolution, measured with the aid of a stabilized He–Ne laser, was determined to be 0.38 ± 0.01 km s^{-1} FWHM (corresponding to a resolving power $R = 790\,000$).

The spectra were extracted from the raw CCD images using the FIGARO data reduction package (Shortridge 1988). Following the arguments presented in section 2.2 of Crawford et al. (1994), the zero level was taken to be defined by the flat core of the apparently fully saturated 'stable' circumstellar absorption component. Wavelength calibration was performed by means of a Th–Ar lamp, and the spectrum was converted to the heliocentric velocity frame.

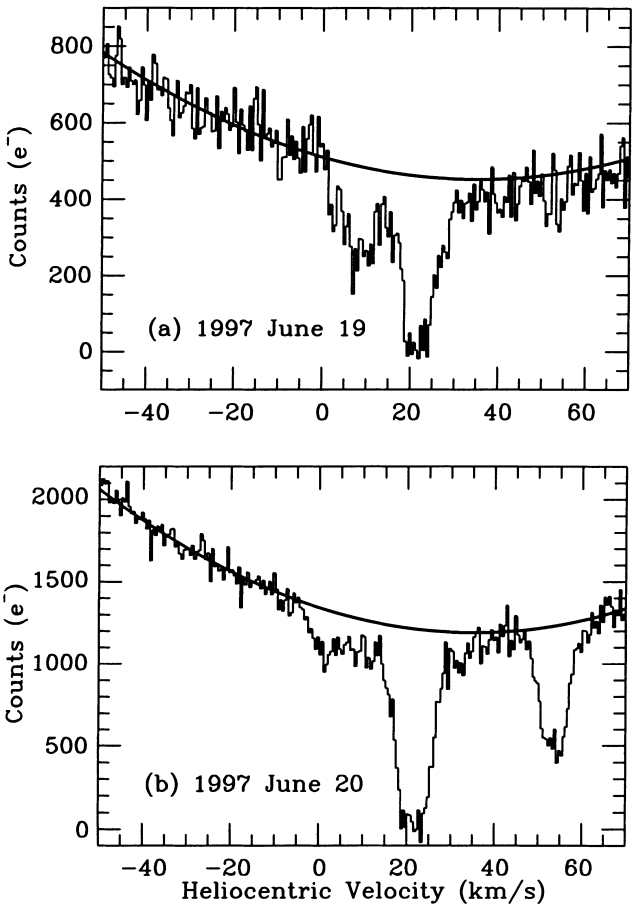

Figure 1. The UHRF observations of the circumstellar Ca II K components for (a) 1997 June 19 and (b) 1997 June 20, both at 20:00 UT. The smooth curve shows a Gaussian fit to the broad photospheric K line.

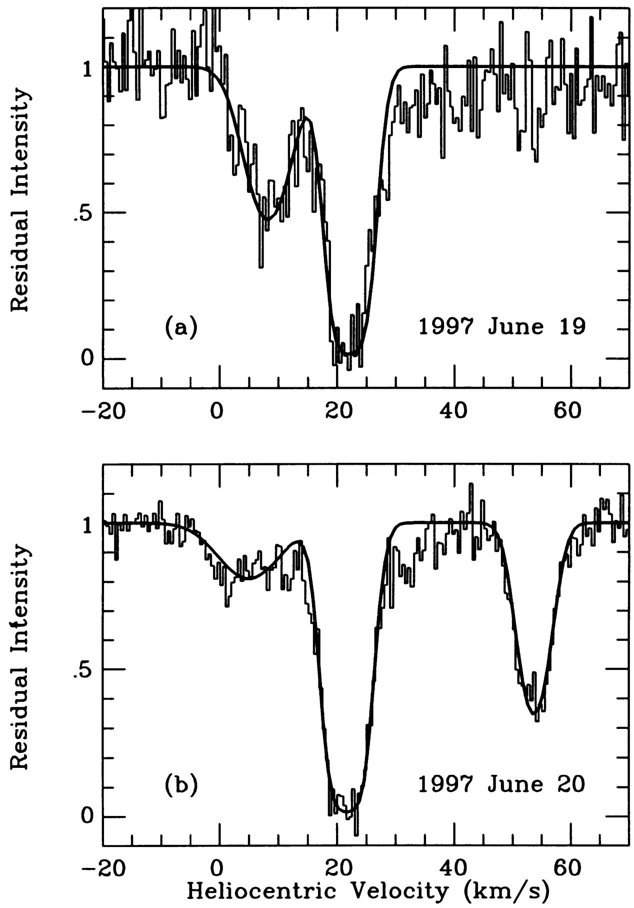

Figure 2. The circumstellar Ca K lines, normalized by dividing by the Gaussian fit shown in Fig. 1. The smooth curves are theoretical line profiles with the parameters given in Table 1. In addition to the three strongest components present on 1997 June 20, we note that there is evidence for an additional weak component at $v_{\mathrm{helio}} \approx +32$ km s^{-1}.

Finally, owing to the poor signal-to-noise ratio of the original data, and the fact that all the circumstellar lines are significantly broader than the instrumental resolution, the raw data were re-binned onto 0.5 km s^{-1} pixels (effectively degrading the two-pixel velocity resolution to 1.0 km s^{-1}). The resulting spectra are shown in Fig. 1.

3 DISCUSSION

It is clear from Fig. 1(a) that on 1997 June 19, β Pic exhibited a strong, transient, absorption component at a heliocentric velocity of about +8 km s^{-1}. This is blueshifted by 14 km s^{-1} with respect to the 'stable' component, which is always present at or near the stellar radial velocity ($v_{\mathrm{helio}} \simeq +22$ km s^{-1}). 24 hours later (Fig. 1b) a blueshifted component was also present, although weaker in strength and somewhat ($\approx$3 km s^{-1}) further to the blue. As it was not possible to monitor the spectrum over the intervening 24 hour period, we cannot tell from these observations whether the weaker component of June 20 evolved from the stronger one of the day before, or whether they have separate origins (but see below). Fig. 1(b) also shows that on June 20 a strong redshifted component ($v_{\mathrm{helio}} \approx +54$ km s^{-1}) was present which had been absent 24 hours earlier.

In order to arrive at a more quantitative comparison between the two observations, a line-profile analysis was performed using the line modelling routines incorporated in the DIPSO spectral analysis program (Howarth et al. 1993). The best-fitting theoretical profiles are shown in Fig. 2, where the observed spectra have been normalized with respect to our estimate of the photospheric line profile (smooth curve in Fig. 1). The line profile parameters of these fits are given in Table 1. Note that if, as argued by Lagrange-Henri et al. (1992), the transient components are actually saturated, but do not reach zero intensity because they only obscure part of the star, the column densities given in Table 1 will be lower limits. Furthermore, Beust & Lissauer (1994) and Hubeny & Heap (1996) have shown that the strengths of these components will, for a given column density, also be a function of the position of the absorbing cloud as projected against the stellar photosphere. As there is no way of determining this information from our observations, this effect has not been included in deriving the column densities given in Table 1.

The 'falling evaporating bodies' (FEB) model, developed by Beust et al. (1990, 1996), explains the velocities of the transient absorption components in terms of the radial velocities of the FEBs as they cross the line of sight on highly elliptical (almost parabolic) orbits about the star. Earlier observations (e.g. Lagrange-Henri et al. 1992), had found a pronounced tendency for the transient redshifted events to occur in the range $30 \lesssim v_{\mathrm{helio}} \lesssim 50$ km s^{-1} (i.e. redshifted by between 10 and 30 km s^{-1} with respect to the star). In order to explain this velocity coincidence in terms of the FEB model, Beust et al. (1990, 1996) and Lagrange-Henri et al. (1992) have argued that the infalling bodies must be following similar orbits about β

Table 1. Comparison of the line-profile parameters obtained for the circumstellar Ca K line towards β Pic on 1997 June 19 and 20; $v_{\rm helio}$ is the heliocentric radial velocity, W_λ is the equivalent width (1σ errors), b is the velocity dispersion parameter (after deconvolution of the instrumental profile), and N is the Ca II column density.

1997 June 19				1997 June 20			
$v_{\rm helio}$ (km s^{-1})	W_λ (mÅ)	b (km s^{-1})	$\log N$ (cm^{-2})	$v_{\rm helio}$ (km s^{-1})	W_λ (mÅ)	b (km s^{-1})	$\log N$ (cm^{-2})
8.2 ± 0.3	52 ± 5	$5.0^{+1.0}_{-1.0}$	$12.00^{+0.10}_{-0.20}$	5.0 ± 0.6	36 ± 4	$7.0^{+2.0}_{-1.0}$	$11.60^{+0.15}_{-0.10}$
22.1 ± 0.2	124 ± 5	$3.5^{+0.5}_{-1.5}$	$12.60^{+0.60}_{-0.20}$	21.7 ± 0.1	136 ± 3	$3.5^{+0.5}_{-1.0}$	$12.60^{+0.60}_{-0.20}$
...	...	...	...	53.7 ± 0.1	67 ± 2	$3.5^{+1.0}_{-0.5}$	$12.00^{+0.10}_{-0.10}$

Pic. Specifically, they found that the longitude of periastron with respect to the line-of-sight, ϖ, must concentrate in the range $\varpi = 20° \pm 10°$, with periastron distances of the order of 20 stellar radii ($\approx$0.16 au). Such a 'family' of objects on similar orbits might be expected to result from the break-up of a single parent body (analogous to the break-up of Comet Shoemaker–Levy 9 prior to its impact with Jupiter in 1994). However, Beust et al. (1996) have shown that, in order to explain the observed velocity range of the redshifted absorption events, it is necessary to postulate the existence of more than one family of FEBs (and therefore more than one FEB parent body).

By varying ϖ, it is possible to generate absorption components at completely different velocities, and if ϖ were randomly distributed among the FEBs we would expect to see as many blueshifted events as redshifted ones. As this is not observed, it appears that there must be some process (e.g. secular or mean-motion planetary resonances; Levison, Duncan & Wetherill 1994 and Beust & Morbidelli 1996) which has aligned the orbits of the FEB parent bodies in a non-random manner. We will now discuss the implications of the present observations in terms of the FEB model.

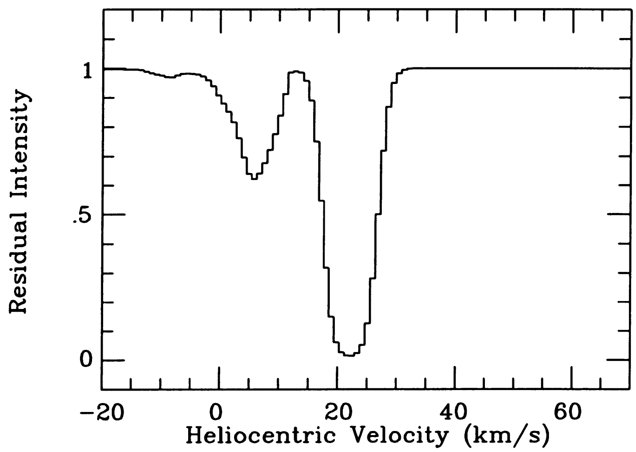

Figure 3. The result of setting the longitude of periastron, ϖ, equal to $-10°$ in the 'falling evaporating body' (FEB) models of Beust et al. (1990, 1996). Note that this value of ϖ results in an absorption component *blueshifted* with respect to the star, very similar in strength and velocity to the blueshifted component observed on 1997 June 19 (cf. Fig. 2a). The strong, 'stable', component at +22 km s^{-1} is not explained by the FEB models, and the best-fitting profile for June 19 (Table 1) is shown to aid comparison with the observations.

3.1 The blueshifted components

As noted in the Introduction, to our knowledge the spectrum obtained on June 19 is the first time that a transient blueshifted Ca II component has been observed with a strength ($W_\lambda \approx 50$ mÅ, $\log N \approx 12.0$ cm^{-2}) comparable to the more frequently observed redshifted events. The FEB model is capable of explaining such blueshifted events by adopting an appropriate value for the longitude of periastron ($\varpi \approx -10°$; see Fig. 3). Indeed, when trying to explain the very weak blueshifted event observed on 1989 October 27, Beust et al. (1991) and Lagrange-Henri et al. (1992) noted that by putting $\varpi \simeq 0°$ it was possible to produce a blueshifted component, but with a strength comparable to the redshifted components; this is exactly the type of event which has now been observed. This strongly suggests that either there is significant variation in the ϖ distribution about the mean value of 20° required to explain the redshifted events (as suggested by Beust et al. 1996), or that there is a population of FEBs on quite different orbits about the star.

The comparison between the blueshifted events of June 19 and June 20 is also of interest. First it must be noted that these two events cannot be produced by the same FEB, because the transit time at $\simeq$20 stellar radii does not exceed 6 to 7 h (note that the transit time of evaporating bodies at a given observed velocity is essentially independent of the other orbital parameters; cf. Beust et al. 1996, section 2.4). Thus, it seems that the second, weaker, blueshifted event must be as a result of another FEB on a similar orbit to the first (i.e. belonging to the same family of objects). Slight differences in ϖ, and/or periastron distance, could then explain the slightly different observed velocities (Table 1). The fact that the second event was found to be weaker could then be because of (i) the FEB responsible for the June 19 event being physically larger; (ii) multiple, but spectrally unresolved, FEBs contributing to the June 19 event; or (iii) a different location of the FEB as seen projected against the stellar photosphere (see Beust & Lissauer 1994; Hubeny & Heap 1996). Finally, we note that the observation of two, generally very rare, blueshifted events on consecutive days argues against them resulting from outliers in the ϖ distribution of the objects responsible for the more common redshifted events, and strongly suggests that they are a result of a separate family of planetesimals within the β Pic disc.

3.2 The redshifted component of 1997 June 20

The sudden appearance of a strong redshifted component on 1997 June 20, when there had been no sign of it 24 hours previously (see Fig. 1), illustrates once again the rapidity with which changes can occur within the β Pictoris disc. This is of course consistent with the FEB model, as the time-scale for a single FEB to cross the line of sight is of the order of 6 h (e.g. Beust et al. 1990). The velocity of this component ($v_{\mathrm{helio}} = +54$ km s^{-1}; i.e. redshifted by 32 km s^{-1} relative to the star) is towards the higher end of the range of velocities found for the transient redshifted components by Lagrange-Henri et al. (1992; cf. their fig. 12). In terms of the FEB model, it can be explained by setting $\varpi = 30°$.

4 CONCLUSION

We have used the UHRF at the Anglo-Australian Telescope to obtain Ca K line spectra of the β Pictoris circumstellar disc on the nights of 1997 June 19 and 20. On the former date a strong absorption component was found at a heliocentric velocity of $v_{\mathrm{helio}} = +8$ km s^{-1}, that is blueshifted by 14 km s^{-1} with respect to the main, 'stable', circumstellar component at $v_{\mathrm{helio}} = +22$ km s^{-1}. This is the first detection of a blueshifted Ca II component with a strength comparable to the more frequently observed redshifted events. Interpreted in terms of the FEB model, this implies an object on a significantly different orbit from those used to explain the more common redshifted events (i.e. $\varpi \approx -10°$, rather than $\approx +20°$).

On the following night a blueshifted component was still present, but its strength had decreased significantly. This event cannot have been owing to the same object responsible for the stronger event of June 19 (because the time needed to cross the stellar disc is $\ll$24 hours), but may be explained by another object on a similar orbit (i.e. belonging to the same 'family'). Indeed, the fact that two, generally very rare, blueshifted events were observed on consecutive days supports the view that FEBs approach the star in discrete families, each family being a result of the disruption of a single parent body.

On the second night a strong redshifted ($v_{\mathrm{helio}} = +54$ km s^{-1}) component was found to have appeared, illustrating once again the rapidity with which changes can occur within the β Pictoris disc. Within the framework of the FEB model, this observation indicates that objects giving rise to redshifted events ($\varpi \approx +30°$) can co-exist temporally with those responsible for the blueshifted events ($\varpi \approx -10°$).

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REFERENCES

Aumann H. H., 1984, BAAS, 16, 483
Beust H., 1994, in Ferlet R., Vidal-Madjar A., eds, Circumstellar dust discs and planet formation. Editions Frontières, Gif-sur-Yvette, p. 35
Beust H., Lissauer J. J., 1994, A&A, 282, 804
Beust H., Morbidelli A., 1996, Icarus, 120, 358
Beust H., Lagrange-Henri A.-M., Vidal-Madjar A., Ferlet R., 1990, A&A, 236, 202
Beust H., Vidal-Madjar A., Ferlet R., Lagrange-Henri A.-M., 1991, A&A, 241, 488
Beust H., Lagrange A.-M., Plazy F., Mouillet D., 1996, A&A, 310, 181
Crawford I. A., Spyromilio J., Barlow M. J., Diego F., Lagrange A.-M., 1994, MNRAS, 266, L65
Diego F., 1993, Appl. Opt, 32, 6284
Diego F. et al., 1995, MNRAS, 272, 323
Ferlet R., Hobbs L. M., Vidal-Madjar A., 1987, A&A, 185, 267
Hobbs L. M., Vidal-Madjar A., Ferlet R., Albert C. E., Gry C., 1985, ApJ, 293, L29
Howarth I. D., Murray J., Mills D., 1993, Starlink User Note, No. 50
Hubeny I., Heap S. R., 1996, ApJ, 470, 1144
Lagrange-Henri A.-M., Vidal-Madjar A., Ferlet R., 1988, A&A, 190, 275
Lagrange-Henri A.-M., Gosset E., Beust H., Ferlet R., Vidal-Madjar A., 1992, A&A, 264, 637
Lagrange A.-M. et al., 1996, A&A, 310, 547
Levison H. F., Duncan M. J., Wetherill G. W., 1994, Nat, 372, 441
Shortridge K., 1988, Starlink User Note No. 86
Smith B. A., Terrile R. J., 1984, Sci, 226, 1421

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