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The Beta Pictoris circumstellar disk

V. Time variations of the Ca II-K line*

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Summary. Observations of the Ca II-K line profile in β Pictoris (A5V) at different epochs show drastic changes on time scales of months, days and hours. At the center of the stellar line, a relatively stable narrow absorption feature is present while, on its red wing, absorptions can appear and disappear. These changes could be related either to a "classical" shell very close to the star or to the circumstellar dust disk much more extended present around β Pic. In this last case, they may be related to cometary-like objects falling on the star. Clearly, further observations are needed to firmly establish if matter is continuously falling back toward the star.

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

1. Introduction

One of the main discoveries from the Infrared Astronomical Satellite (IRAS) was the existence of several nearby stars having a far-IR thermal emission in excess relative to the Rayleigh-Jeans limit of a Planck distribution (Aumann et al., 1984). Interpreted as circumstellar material consisting of unusually large solid particles, such a dusty disk has, up to now, been clearly imaged around only one star, namely β Pictoris (HR 2020, A5V) at 0.89 μm (Smith and Terrile, 1984). Extending to about 500 au, and seen nearly edge-on, the β Pic dust disk was a favorable candidate for absorption line studies. Indeed, a further gaseous component was revealed through its UV Fe II lines (Kondo and Bruhweiler, 1985) and visual Ca II and Na I ones (Slettebak, 1975; Hobbs et al., 1985, Paper I; Vidal-Madjar et al., 1986, Paper II). Furthermore, investigating other IRAS stars and "classical" long-known shell stars, Hobbs (1986, Paper III) concluded that β Pic was, among his small sample, the only star to be surrounded by a detectable disk of *both* dust and gas.

Another peculiarity of that star was pointed out by Kondo and Bruhweiler (1985) in IUE observations: the absorption lines related to the gaseous shell are strongly changing with time. This has been confirmed with more recent IUE data by Lagrange et al (1987, Paper IV), who also showed that the observed variations seem to take place always at a redshifted position relative to the stellar radial velocity. Since furthermore Fe II* and Fe II** lines are present in this changing gaseous shell, it should be confined to within 1 au from the stellar surface and possibly even much closer.

We report here further time variability, now in the calcium II-K line observed from the ground (Sect. 2) and we propose possible explanations (Sect. 3).

2. Observations

Several high-resolution spectra of β Pic at the K line of Ca II have been obtained at different epochs since 1984. They are listed in Table 1.

The observations conducted at the Mc Donald Observatory were acquired with the echelle grating and the Digicon detector at the 2.7 m reflector (Paper III). The data collected at the European Southern Observatory (ESO) at La Silla, Chile, were obtained with the Coudé Echelle Spectrometer fed by a 1.4 m telescope and equipped with a cooled Reticon detector (Ferlet and Dennefeld, 1984). At both sites, the instrumental resolution (FWHM) was equivalent to 3 km s^{-1} and the internal accuracy of the wavelength calibration was ± 0.2 km s^{-1}. All the spectra were then corrected for the Earth's motion.

Table 1. Log of observations and equivalent widths for the Ca II-K circumstellar absorption feature seen toward β Pic

Date	Site	$W_\lambda(K)$[a] (m Å)
1984 October 20	ESO	86 ± 4
1984 November 13	Mc Donald	115 ± 20
1985 March 9[b]	ESO	90 ± 20
1985 October 6	Mc Donald	154 ± 25
1986 January 10	ESO	110 ± 12
1986 January 11	ESO	160 ± 16
1986 January 17	ESO	112 ± 12[c]

[a] Total W_λ for both the deepest and the redshifted (when present) features.
[b] Bad seeing conditions.
[c] Average value from eight consecutive spectra.

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* Partly based on observations collected at the European Southern Observatory, La Silla, Chile.

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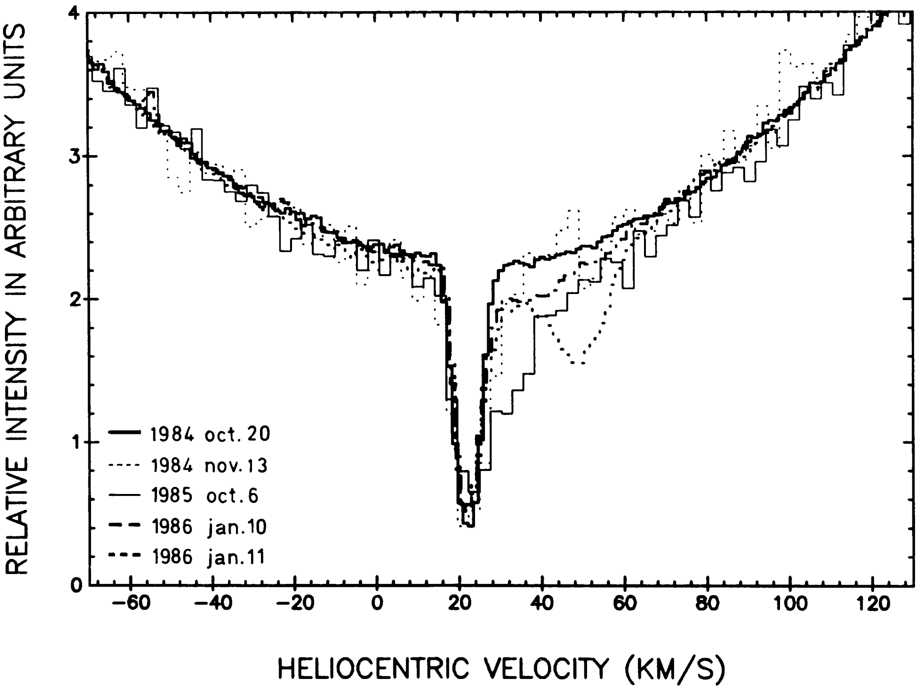

Fig. 1. Enlarged spectra of β Pic in the region of the circumstellar Ca II-K line, in an heliocentric velocity scale. They have been normalized in order for the "continua" (the stellar line widened by rotation) to coincide. To avoid confusion due to its much lower signal to noise ratio, the 1985, March 9 spectrum has not been plotted. Variations during 1986, January 17 are studied in Fig. 2

Enlarged portions of spectra near the K line are shown in Fig. 1. Their "continua" (the stellar K-line) have been appropriately shifted in ordinates in order to coïncide to be superimposed. Changes in the profile of the narrow circumstellar absorption are obvious in both sets of observations, on scale of several months. Moreover, the two spectra from the January 1986 run taken at one day interval show an obvious variation at that time scale. In all spectra, the strongest absorption occurs at a similar velocity, corresponding nearly to the center of the broad stellar K line widened by rotation (Papers I and II). This suggests apparently the presence of a central core, stable in velocity and giving rise to a stable profile slightly less steep in the red than in the blue. But this also shows that essentially all the observed changes in the present sample arise redshifted relative to the stellar radial velocity. We face therefore a phenomenon comparable to what is seen in the UV lines (Paper IV).

The velocity range covered by the observed changes is about $40\,\mathrm{km\,s^{-1}}$. The equivalent widths of the whole lines are given in Table 1, taken from the data used for Papers I and II or measured on new spectra. Within the error bars, there is no obvious variation, except for the 1985 October and 1986 January 11, observations which seem to evidence a clear increase.

We have also observed sequentially during the 1986 January 17, night the Ca II-K line profile and have detected changes over shorter time scales, of the order of hours. Because these changes are less pronounced we have plotted on Fig. 2, again as a function of heliocentric velocities, the intensity ratio between each spectrum and the first one thus used as a reference.

This type of presentation directly reveals the spectral variations during the observational sequence (more than three hours). What is clearly seen in Fig. 2, is that a weak red component is present, slowly shifting in time further in the red by about $5\,\mathrm{km\,s^{-1}}$ over few hours, while its equivalent width seems to slightly rise about from 10 to 20 mÅ and its b-value to decrease about from 10 to $5\,\mathrm{km\,s^{-1}}$.

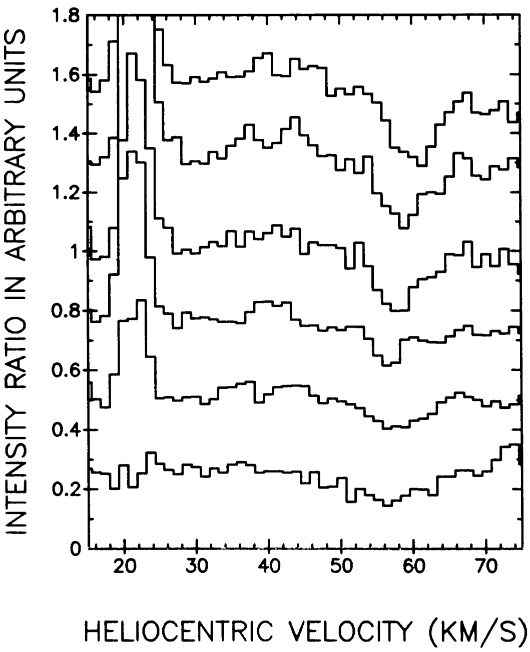

Fig. 2. Spectral variations in the circumstellar Ca II-K line toward β Pic. Six consecutive spectra recorded on January 17, 1986, have been divided out by a same spectrum taken just before and used as a reference. To avoid confusion, the flat "continua" have been shifted proportionally to the time elapsed between the spectra. A red absorption feature is clearly seen to slowly move toward higher velocities (from the bottom to the top, nearly three hours elapsed)

3. Discussion

Three main observational facts must be underlined:

i) Up to now, *all* observations in the visible (this paper) as well as in the UV (Paper IV) reveal only redshifted variations.

ii) The maximum redshift observed in the case of Ca II is of the order of 40 km s^{-1}, a value significantly smaller than the one observed in the UV for Mg II and Fe II (Paper IV). This could be simply due to observations made at different epochs.

iii) One red feature observed in Ca II over few hours seems to slightly increase in strength, to become narrower and to shift slowly further to the red.

Bearing in mind these points, we suggest now some possible modelisations, although none seems to explain in a satisfactory way all the observations.

3.1. A pure stellar atmospheric phenomenon

A growing body of high resolution, high signal to noise observations now reveal photospheric line profile variations and the presence in their cores of evolving multiple narrow absorption components in early type supergiants (see e.g. Baade and Ferlet, 1984, and references therein). These are interpreted as the signature of non-radial pulsations, and Baade and Ferlet (1984) even suggest a relation with the stellar rotation in the sense that rapid rotation facilitates the detection of this type of pulsations (note that the $v \sin i$ of β Pic is 139 km s^{-1}).

There exist several other groups of pulsating stars. Among them, the δ Scuti stars have spectral types A or F and luminosity classes between III and V. The star β Pic (A5V) could therefore be a member of this group. These groups are in general characterized by the presence of emission features, sometimes very weak, explained by the propagation of shock waves. A first inspection of the wings of our Ca II spectra as well as of Hα spectra taken in October 1984, March 1985 and January 1986 does not reveal any emission.

However, for both early-type supergiants and δ Scuti stars, the time scales of their periodic variations and their behaviour are very similar to the one reported in Fig. 2. Nevertheless, in the frame of that explanation, there is no reason to detect these changes only on the red side of the line core as it is the case in Ca II and in UV lines (Paper IV).

It is clear that our present survey is still too rough in time to definitely rule out the possibility of variations occurring at the stellar surface, but the present observations certainly do not favour this type of explanation.

3.2. A shell phenomenon close to the stellar surface

Previously classified as a shell star (Slettebak, 1975), β Pic shows indeed a Ca II-K line profile similar to those of other A-type shell stars, and particularly to the ν^2 Boo one which also seems to present perturbations on the red side of the deepest line core (Paper III).

In their study of normal A-type stars, Abt and Moyd (1973) observed a number of shell spectra, sometimes variable in strength or velocity, in stars having a projected rotational velocity $v \sin i \geq$ 175 km s^{-1}, no emission lines, no known Hα emission or hydrogen absorption cores, as in the case of β Pic (its $v \sin i$ is 139 km s^{-1} but we further know that it is seen edge on). They concluded that the shell stars could likely be rapid rotators that are in, or have recently passed through, a stage of contraction during which an absorbing disk very close to the star might develop. Since the velocity extent of the Ca II perturbation seen in β Pic is 40 km s^{-1}, largely below the stellar escape velocity, the corresponding gas was not able to escape from the star; it should thus fall back on it, and this could explain the observed redshift (this is also true for Mg and Fe since their velocity limit is $\sim$100 km s^{-1} (Paper IV), also clearly below the stellar escape velocity). If at other epochs permanently blue shifted material is detected, it will strenghten this possibility.

One can also suggest a plausible mechanism (related to a more or less "classical" circumstellar shell) for not detecting the blueshifted, rising material: the rising process could take place only over the stellar poles, the material fall-back occurring on the contrary over the whole stellar surface. It is clear that this interpretation will be strenghtened only if observations of similar shell stars seen pole on reveal blueshifted components.

3.3. A phenomenon related to the dust shell present at larger distances from the star

In the framework of the model presented in Paper II, the core of the Ca II-K narrow absorption line in β Pic is due to the gas associated with the inner disk of dust imaged by Smith and Terrile (1984), at about 0.5 au from the star, and enriched in calcium because of dust grain evaporation. One therefore expects a relatively stable central core shape, as observed.

In Paper IV, it was suggested that material from the dusty disk is continuously falling down toward the star. To explain the drastic changes, one has then to invoke strong inhomogeneities in the inward motions present within 0.5 au from the star. If these inhomogeneities are stable, their orbital period should then produce periodic perturbations of the line. The orbital velocity at 0.5 au from β Pic being about 100 km s^{-1}, one can expect periods of the order of hours or less if the inhomogeneities present sizes comparable to or smaller than the stellar size itself. But sporadic changes may also be observed, due to unstable inhomogeneities. However, in the frame of that explanation it is difficult to understand simply the strength of the observed redshift, too important for in-orbit material, i.e. with velocities perpendicular to the line of sight.

On the other hand, if we interpret the observed Ca II redshift as due to a discrete event of freely infalling material (large bodies like cometary nuclei could plausibly account for such observations), it is possible to evaluate the acceleration of this matter $\Delta v/\Delta t$ which is of the order of 0.5 m s^{-2} (see Fig. 2), a value which corresponds roughly to a distance of 0.2 au above the stellar surface. This point, although possibly due to a coïncidence, is quite interesting and may indicate that, at least partly, this type of modelisation is the best suited to explain all the observations since further more one may note from Fig. 2 that the equivalent width increases during the fall, a prediction compatible with the picture of a cometary-like body evaporating more and more while falling on the star.

Only a permanent survey of the recorded changes will allow one to derive an eventual period and to confirm or not the above scenario.

4. Conclusion

We have shown that variations on time scale of months, days and hours do occur in the line profile of the Ca II-K circumstellar absorption observed toward β Pictoris. Also it is confirmed that these changes appear on the red wing of a relatively stable central core.

Although such changes might originate in the stellar atmosphere itself, it seems at the present stage more likely that such a behavior is related to a gaseous shell, either very close to the star or in the inner part of a much more extended dust disk. In the first case, β Pic should be in that respect similar to other A-type shell stars, the recorded phenomenon being disconnected from the dust disk or the Na I gas shell (Paper III) which is far away (Paper II) and not affected by variations as it has been observed in Paper II. In the other case, if inhomogeneities are proved to be real, they could be the signature of small cometary-like condensations present inside the dusty disk, infalling from time to time on the star, and possibly related to the mechanism of planetary formation.

Finally, it is worthwhile to note that the two last scenarios are certainly not incompatible. It is possible that β Pic is a unique star having at the same time a "classical" very closeby shell along with an unrelated dusk disk much more extended and containing also some gas as seen in Na I. That could explain why A-shell stars were not detected by the IRAS satellite and why other IRAS stars similar to β Pic do not present any detectable Ca II absorption (Paper III).

Only further observations and detection of a period will help in clarifying the β Pic puzzle.

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