Dust and gas around λ Bootis stars

I. Kamp and H. Holweger

Institut für Theoretische Physik und Astrophysik
Universität Kiel
Germany

Abstract. High-resolution spectra of λ Bootis stars reveal the presence of circumstellar gas for example in the Ca K line.

The example of the normal A star β Pictoris shows, that the narrow stable absorption component in Ca K can be reproduced using appropriate disk models and a calcium underabundance in the circumstellar gas of a factor of ~ 30.

Similar models are suggested for the group of metal-deficient λ Bootis stars, but the observational material is still very poor.

Key words: Stars: circumstellar matter – Stars: chemically peculiar – Stars: individual: β Pictoris

1. Introduction

High-resolution spectrometry and NLTE analysis of λ Bootis stars reveals the metal-deficient nature of this small subgroup of main-sequence A stars (Venn & Lambert 1990, Holweger & Stürenburg 1993, Stürenburg 1993). Venn & Lambert (1990) suggested that the abundance anomalies of these stars are due to accretion of circumstellar (CS) gas, which is depleted in condensable elements.

Evolutionary tracks for the λ Bootis stars and a recent high-S/N search for circumstellar Ca K lines raise the question of a possible pre-main-sequence evolutionary status for these stars (Gerbaldi et al. 1993, Holweger & Rentzsch-Holm 1995, Paunzen et al. 1998). In this case the circumstellar gas may have remained from the star formation phase.

The disk models presented in the following section are in close analogy to those for more massive disks around T-Tauri stars. A short discussion has been given by Rentzsch-Holm, Holweger & Bertoldi (1998).

2. Circumstellar disk models

The gas density distribution of our model corresponds to thin disks in hydrostatic equilibrium:

$$\rho(r) = \rho_\mathrm{i} \cdot \left(\frac{r}{R_\mathrm{i}}\right)^{-\epsilon} \; e^{-(h/Hr)^2} \;, \qquad (1)$$

where $R_{\rm i}$ is the inner disk radius, r the radial distance from the star, h the vertical disk height above the disk, and $H \equiv \sqrt{2}h_0/r \approx$ constant is the scale height scaled to the radius. The outer disk radius, $R_{\rm o}$, and total disk mass then determine the midplane density at the inner disk radius, $\rho_{\rm i}$. The dust responsible for UV absorption is assumed well mixed by turbulence, and $H_{\rm gas} = H_{\rm dust} \sim 0.2$ (Pringle 1981).

The disk temperature is derived from radiative equilibrium calculations using dust opacities from Henning & Stognienko (1996) for a mixture of various grain materials and sizes of up to 5 μm.

Figure 1 shows the density distribution in a β Pictoris model. The disk extends from 40 to 480 AU and comprises a total mass of 46 earth masses ($M_{\rm gas} : M_{\rm dust} = 100$). The parameters are chosen in accordance with the results of Chini et al. (1991).

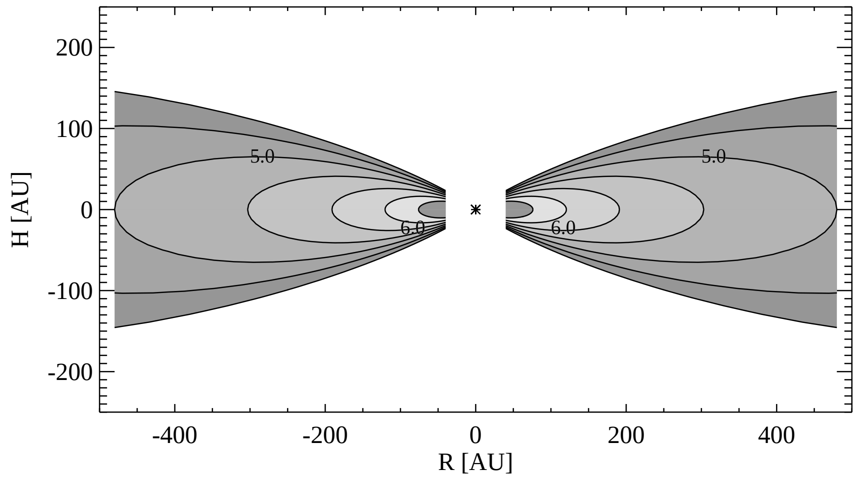

Figure 1. Density distribution in the β Pictoris model: $R_{\rm i}$ = 40 AU, $R_{\rm o}$ = 480 AU, $M_{\rm tot}$ = 46 $\rm M_E$, ATLAS9(8000, 4.0, 0.0), $R_* = 1.7 R_\odot$. Shown are isodensity lines on a logarithmic scale. The outer boundary is defined by the disk density dropping to typical values of molecular clouds, 10^4 cm^{-3}

3. The circumstellar Ca II-K lines

Holweger & Rentzsch-Holm (1995) found narrow absorption components in 5 of the 11 λ Bootis stars studied. This suggests that the λ Bootis phenomenon is related to the presence of circumstellar gas. Because of their faintness λ Bootis stars were hardly detectable by IRAS and hence information on the presence and extension of circumstellar dust and its mass is very poor.

In the following the prominent A star β Pictoris is taken as an example for the formation of a narrow absorption component in a circumstellar disk even though β Pictoris itself does not belong to the group of λ Bootis stars (Holweger et al. 1997).

The ionization equilibrium of Ca in the disk is determined by photoionization due to the unshielded stellar radiation field (Verner et al. 1996) and recombination via collisions with electrons (Spitzer 1978). Line broadening is due to thermal velocities.

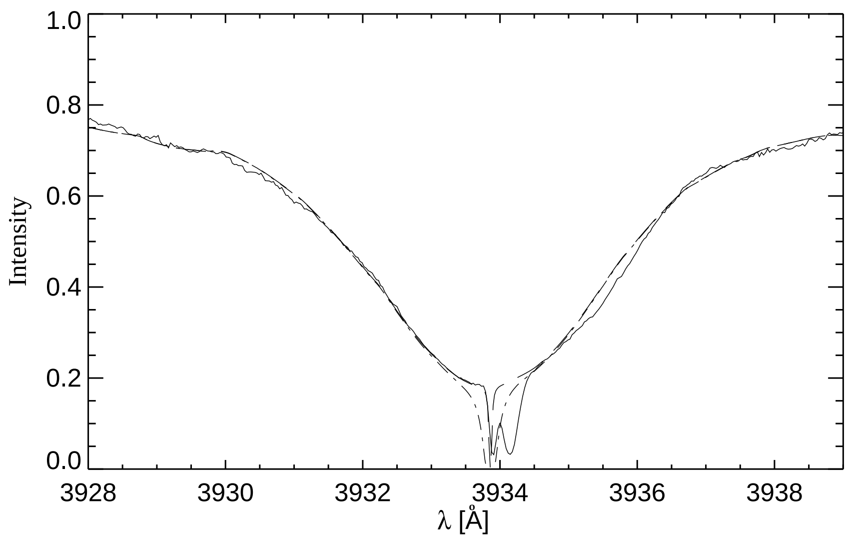

Figure 2. Core of the Ca K line in β Pictoris. Solid line: observation 1993 JAN 25, see Holweger & Rentzsch-Holm (1995); dashed line: photospheric calcium abundance [Ca/H]= 0.02, circumstellar calcium abundance [Ca/H]= -1.5; dashed-dotted line: photospheric calcium abundance [Ca/H]= 0.02, circumstellar calcium abundance solar

Fig. 2 shows the β Pictoris Ca K line recorded in 1993 with the Coudé Echelle Spectrograph of the ESO 1.4-m CAT telescope at a resolving power of 50 000. The dashed line represents a synthetic spectrum calculated with an ATLAS9(8200, 4.24, 0.0) model atmosphere, a calcium abundance of [Ca/H]= 0.02 and a $v \sin i$ of 132 km s^{-1} (Holweger & Rentzsch-Holm 1995). The narrow absorption component at the bottom of the rotationally broadened photospheric line results from absorption by ionized calcium in the circumstellar disk model described in Sect. 2. The disk is assumed to be seen edge-on and calcium strongly depleted in the disk, [Ca/H]= -1.5. The dashed-dotted line represents the same model with a solar calcium abundance in the disk.

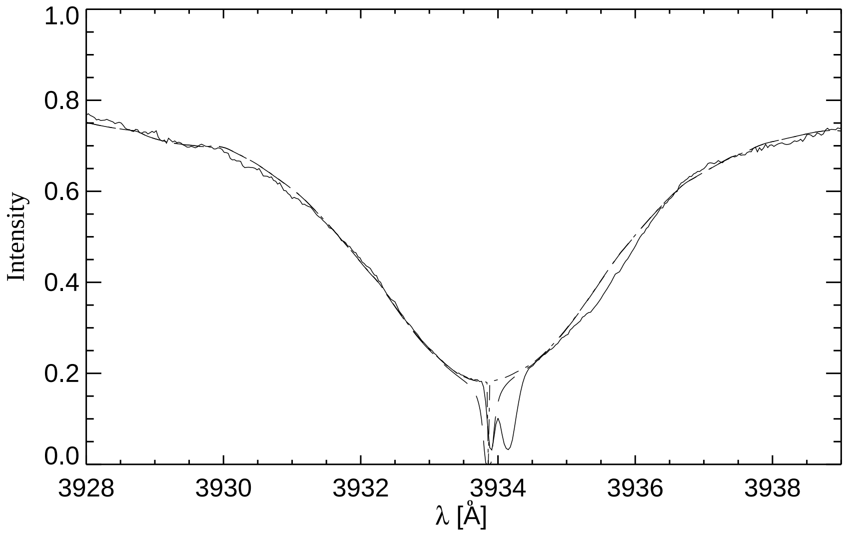

Figure 3. Core of the Ca K line in β Pictoris. Solid line: observation 1993 JAN 25, see Holweger & Rentzsch-Holm (1995); dashed line: solar calcium abundance in the disk (like dashed-dotted line in Fig. 2) but $\beta = 10°$; dashed-dotted line: solar calcium abundance in the disk but $\beta = 30°$

Fig. 3 shows the variation of the circumstellar line profile with increasing aspect angle β ($\beta = 0$ corresponds to "edge-on"). Observation at larger β results in a narrower CS line profile, because the density strongly decreases with increasing distance from the equatorial plane. Hence this has the same effect as decreasing the calcium abundance. The CS component will disappear if the line of sight to the star does not intersect the disk as it may be the case for Vega, which seems to be a fast rotating λ Bootis star seen pole-on (Gulliver, Hill & Adelman 1994, Holweger & Rentzsch-Holm 1995).

4. Conclusion

For β Pictoris the stable component of the CS absorption line in Ca K can be explained by absorption in a gaseous disk in Keplerian rotation around the star. Ca II is the dominant ionization stage as already pointed out by Lagrange et al. (1995). Since the inclination of the disk is only a few degrees (Smith & Terrile 1984), the results suggest that calcium is underabundant by a factor of ~ 30 in the circumstellar disk around β Pictoris.

The model presents the possibility to quantitatively study the circumstellar lines observed in several λ Bootis stars. Nevertheless further information such as ISO observations or radio observations are needed to constrain the free parameters of the model, like disk masses and extensions.

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