# Detection of calcium abundance stratification in Ap stars

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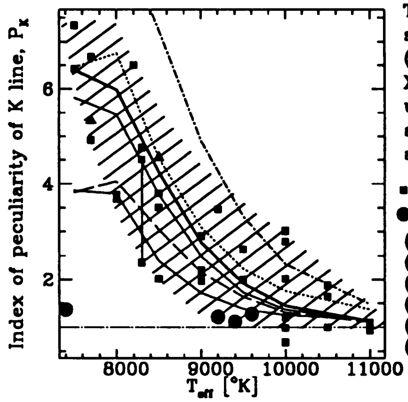
**Abstract.** We report the discovery of a systematic and large calcium abundance stratification in cold Ap stars. These detections are in very good agreement with diffusion theory and set stringent upper limits on turbulent processes.

## 1. Context and observations

The peculiarity of the Ca II K line at 3933 Å (see Fig.1 of Babel 1993b) is a well-known but unexplained feature of Ap stars (since Babcock 1958). On the theoretical side, abundance stratification is a major prediction of radiative diffusion (e.g. Michaud 1970) and has to be tested.

We made a high resolution spectroscopic survey of the Ca II K and H lines at 152cm of OHP. It includes 28 Ap stars with $7500 \lesssim T_{eff} \lesssim 11000$ K (3 with $vsini \simeq 100$ km/s, 2 rapidly oscillating Ap (roAp)). The K line profile was parametrized to allow quantitative study of the K line shape.

Our goal was to discriminate spotted-nonstratified models from stratified models on a statistical ground as any peculiar K line can be reproduced either by abundance stratification or by abundance spots (Babel 1993a)




The various curves are for step-like abundance stratification. (X,Y,Z) is for an abundance of X times the solar abundance in the upper atmosphere. Y for the abundance step in $\log\tau_{5000}$. Z is as X, but for the deeper region

- ▪ Ap stars
- ● standard stars

(0.02,10,−1.3) heavy curve,
(0.02,10,−1.0) short−dashed
(0.02,10,−0.5) solid
(0.02,50,−1.0) dotted−dashed
(0.02,50,−0.5) dotted
(0.10,10,−1.0) long−dashed

Fig. 1.

## 2. Results and Discussion

In various diagrams relative to the shape of the K line (see Babel 1993b), Ap stars follow a very different trend than normal stars. In particular, we did not find Ap stars with nonpeculiar profiles, $P_K \simeq 1$ for $T_{eff} < 9000$ K



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(Fig. 1). Our results exclude statistically nonstratified-spotted models as an explanation of the peculiar shape of the K line. NLTE effects can also be excluded (Babel 1993b). In contrast, the observations are well explained by a large Ca stratification with decreasing abundance towards the surface.

Stringent additional test comes from the study of the blend $H_\epsilon$-CaII H and gives another proof of calcium abundance stratification (see Fig. 2.a).

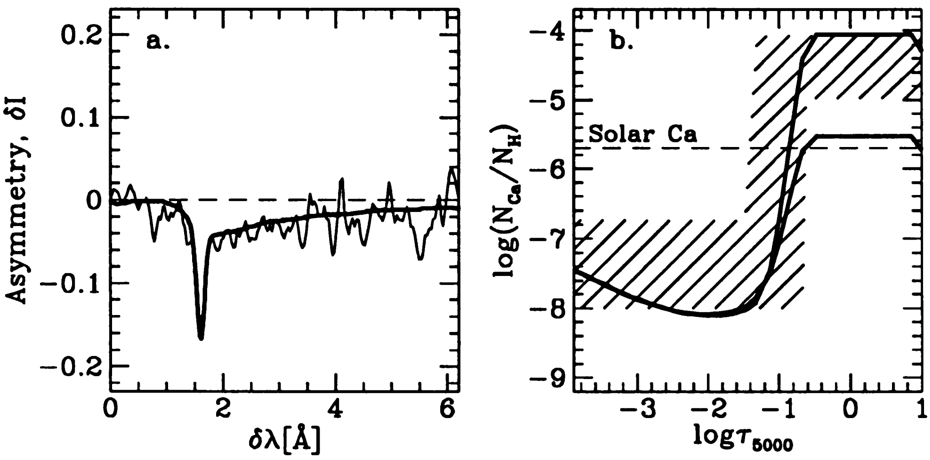


Fig. 2. **a.**Asymmetry of $H_\epsilon$ in HD 204411. Heavy line: stratified model (0.005,10,-1.3) (see Babel 1993b). Thin line: observation at DAO by Adelman (private comm.)**b.** Abundance of Ca as a function of optical depth. The heavy curves are for the diffusion-mass loss model of 53 Cam with $\dot{M}$ =3 $10^{-15}$ $M_\odot yr^{-1}$ (upper curve) and $\dot{M}$ =0 (lower curve) (Babel 1992). The hatched zone is the range of stratification of Ca (step-functions) obtained from the Ca II K and H line for Ap stars with $T_{eff} \leq 9000$ K.

The results on Ca abundance stratification deduced from the Ca II K and H lines (for an assumed step-function) for Ap stars with $T_{eff} \lesssim 9000$ K are summarized by the shaded area in Fig. 3. We obtain that a large Ca stratification, with a variation by 2 dex of the Ca abundance in the line-formation region, seems very common in Ap with $T_{eff} \lesssim 9000$ K, without effects to first order from rotational velocity or from pulsation for the roAp.

We obtain a very good agreement with equilibrium abundance distributions from the diffusion model (Babel 1992). These results indicate a very large stability of the photospheric regions.

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