The A-Star Puzzle
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Testing the presence of lithium on the surfaces of cool Ap stars

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Abstract. The possibility of a quite high Li abundance in the Ap stars was first raised by Wallerstein & Merchant (1965). Since then many studies investigated the problem of Li. The more recent observations in the lithium region indicate that in some Ap stars the λ6708 feature is variable and this variability can be explained by the existence of Li rich spots on the stellar surface. Atomic data for the Ce II λ6708.099 were released by the D.R.E.A.M. database in 2002. The line was used to identify the prominent suspected Li-feature in post AGB stars and might as well be responsible for the absorption feature in Ap stars. Recent studies have mentioned this possibility, but it has yet to be investigated in more detail. Other physical phenomena, such as the occurrence of a partial Paschen-Back effect in the presence of magnetic fields, as well as possible hyperfine structure splitting of some Rare Earth transitions, must be taken into account to provide correct line identifications in the wavelength region around the Li-doublet at λ6708. We discuss a possible strategy to clarify the presence of Li in Ap stars.

Keywords. Stars: chemically peculiar, line: identification

1. Introduction

The identification of the Li I resonance doublet at λ6707.76 and λ6707.91 in the past was doubtful because of the relatively low spectral resolution and S/N ratio. More recent observations in the lithium region indicated that the Li doublet is possibly present in the spectra of some Ap stars (Faraggiana *et al.* 1996). However, the presence of several lines of rare earth elements (REE) in the same spectral region suggested the possibility that the main component of the Li blend may be due to some unidentified line. The feature centered around λ6708 did not have the same profile in all the stars. Moreover, the central wavelength showed a redward shift $\leqslant 0.2$ Å , varying from star to star. Polosukhina *et al.* (1999) presented the results of the study of the behavior of the Li feature with rotational phase in 8 Ap stars. For four stars in the sample, HD 83368, HD 60435, β CrB and HD 188041, wavelength variations with the rotational period have been discovered and the conclusion has been made that the Li feature can be identified as the resonant Li I doublet and the variability of the feature is explained by the existence of Li rich spots on the stellar surfaces. Consequently, all later work on the Li feature has been devoted to the modelling of the Li abundance using the technique of Doppler Imaging. Two years ago a new Ce II line list has been released by D.R.E.A.M. and it was shown by Reyniers *et al.* (2002) that the Ce II line at λ6708.099 was an obvious candidate to identify the "shifted Li line" in the s-process enriched post-AGB stars and that there was no need to invoke special non-standard mixing during the AGB evolution to explain the claimed high abundances of Li in these stars. As Ce is usually overabundant in Ap stars and a similar redward shift of about 0.2 Å compared to other photospheric lines is

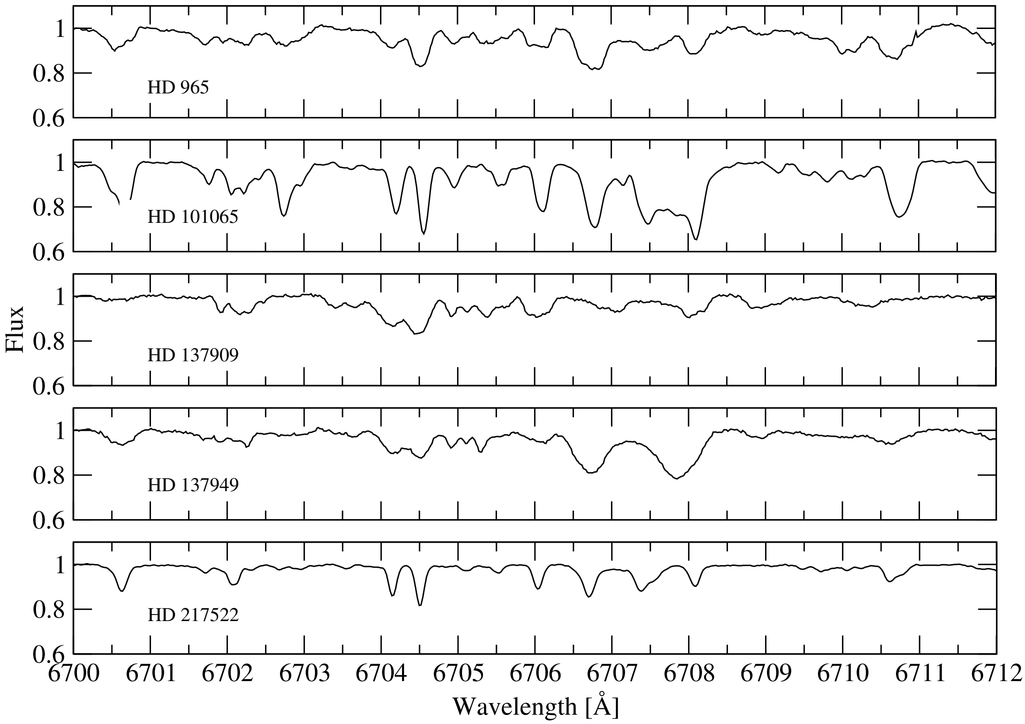

Figure 1. The region around the feature at λ6708, so far identified as Li, is presented for five typical Ap stars with different magnetic field strengths. The strong blending illustrates that the highest spectral resolution observations are necessary to settle the question of the line identification.

frequently observed, it is important to finally determine if the line at λ6708.1 discussed in the literature as due to Li is in fact Ce II line at λ6708.099 or possibly another yet unidentified REE line. In the following we present a strategy which will help to clarify the question if Li is indeed observed in Ap stars and how more reliable abundances could be determined.

2. Observational requirements

Generally, correct line identifications in a crowded region like the one around λ6708 in Ap stars, requires observational material of highest possible resolution and S/N. Fig. 1 shows UVES spectra of 5 Ap stars to illustrate the high complexity of the blend-feature even at very high resolution. For this project, we plan to observe a small sample of Ap stars with low v sin i for which the presence of Li rich spots on the surface is discussed in the literature with the ESO-VLT echelle spectrograph UVES, at highest ($R = 0.8 \times 10^5$ in the blue and $R = 1.1 \times 10^5$ in the red) spectral resolution and high signal-to-noise ratio (>300) over a large spectral range (λλ3000-10000). Several spectra should be obtained for each star, distributed over its rotational cycle, to obtain information about the surface distribution of various elements and their variations with rotational phase.

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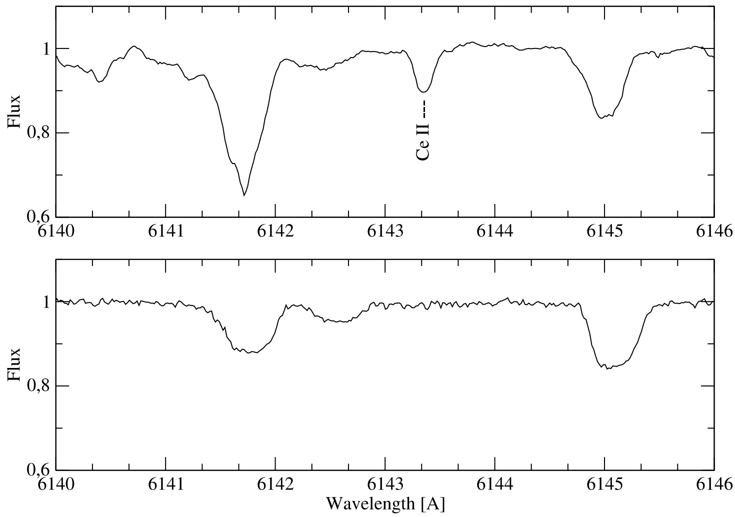

Figure 2. Comparison of the region around Ce II λ6143.376 which is frequently used for abundance analyses in Ap stars. In the Li-rich star HD 137909 (upper panel), this feature can be modelled using a 2 dex overabundance of Ce, whereas HD 128898 (lower panel), classified as a Li-deficient Ap star by Polosukhina *et al.* (1999) does not show an overabundance.

3. Abundance analysis of blend components

The latest atmospheric models based on ATLAS9 (Kurucz 1993) and magnetic synthesis techniques, can be used to perform detailed abundance analyses. Since previous studies have mainly considered only short spectral intervals for their analyses, the large wavelength range covered by UVES will allow us to derive the most accurate abundances of all elements contributing to the spectra in the λ6708 region. Because of the severe crowding in the "Li-region" (Fig. 1), it is clear that reliable abundances for any of the elements cannot be obtained using only this part of the spectrum, hence the derived Li abundance using only one Li line may not be considered reliable.

The feature at λ6708 is blended with lines of the REE ions Ce II, Pr III, Nd II and Sm II. In the region λλ3300-6000 many Ce transitions can be used for abundance determinations, not only from blended features, but also from uncontaminated lines. The nature of the correlation between abundance and rotational modulation of Ce and the appearance, shape and shifts of the Li-doublet will be an important indicator for a possible misidentification of the latter. The technique of Doppler Imaging, which was already applied in other Li-related studies, will be used to compute abundance maps of all species involved in the blend feature, using a large number of lines of each element, accessible in our observations. In this way, a possible correlation between the positions of the suspected Li-spots and the surface distribution of other elements can be investigated. A simple test (Fig. 2) indicates a possible correlation between "Li-deficiency" and Ce abundance, i.e., a star classified by Polosukhina *et al.* (1999) as Li-deficient show no significant overabundance of Ce in its spectrum. Element abundances derived from the whole available spectral region will be used for further, more detailed modelling of the λ 6708 feature in question.

4. Atomic parameters

Improved atomic parameters are crucial ingredients for deriving accurate abundances for many REE. Since an accurate gf value is still missing for Ce II λ6708.099 and its

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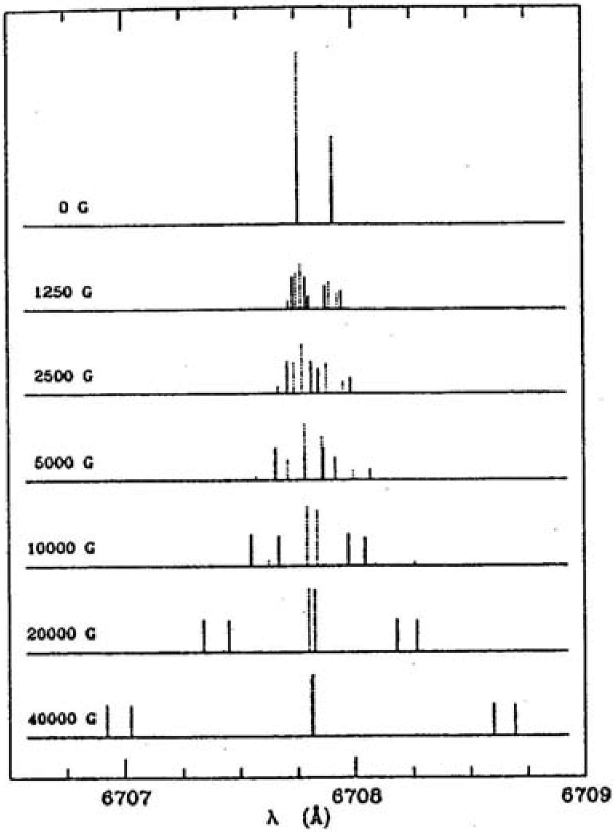

Figure 3. Splitting of ^{7}Li I λ6707.761 and λ6707.912 in magnetic fields of various intensities, orthogonal to the line of sight. Line components are represented by bars whose length is proportional to the relative strenth of the component. Solid bars: σ-components, dotted bars: π-components (taken from Mathys 1991).

Landé g value is unknown, it is not clear at all, if this line could be responsible for the absorption feature at this wavelength. To study REE abundances, we should also take into account possible isotopic shifts, line broadening due to hyperfine structure splitting and the effect of hyperfine structure on Zeeman patterns. As soon as the required data become available via various databases, e.g., VALD3, we will be able to include them in our calculations.

5. Line synthesis including partial Paschen Back effect

In magnetic Ap stars, a number of spectral lines are formed in the regime of the partial Paschen-Back (PPB) effect. Mathys (1991) showed that especially the Li doublet at λ6708 is severely affected. As can be seen in Fig. 3, in presence of magnetic fields > 1 kG the PPB effect will cause significant asymmetries in the line profiles. The realtive strengths of the split components depend on the magnetic field orientation as well as on its strength. The line profiles we see in stellar spectra consist of a combination of patterns, like the ones shown in Fig. 3. Hence, in a real Li feature, significant asymmetries of the line profiles should be detectable and the effect has to be included in the modelling of these lines. In previous studies, the PPB effect has been usually neglected.

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