

OBSERVATIONS OF MAGNETICALLY SPLIT LINES IN Ap STARS *)

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INTRODUCTION

Ap stars whose spectral lines are resolved in several magnetically split components are of particular interest, because their magnetic field can be diagnosed with unrivalled precision, in an essentially approximation-free manner. We are pursuing a systematic programme of search and study of such stars. At present 25 of them are known, of which 13 have been discovered in the course of the present project (Mathys 1990, hereafter Paper I; Mathys & Lanz 1992, hereafter Paper II; this paper).

Up to now, we have obtained observations of 22 of these Ap stars with resolved magnetically split lines. We have recorded high-resolution spectra of a region containing, among others, the three lines Cr II λ 6147.154, Fe II λ 6147.741, and Fe II λ 6149.258. The Zeeman patterns of these three lines are, respectively, close to a triplet, close to a quadruplet, and a doublet. The doublet Fe II λ 6149.258 is particularly interesting, because of its large Landé factor (2.7): it can be resolved even in stars with fairly modest fields.

The observations were performed with various instrumental configurations: OHP 1.5 m telescope + AURELIE spectrograph + Thomson "barrette" ($\lambda/\Delta\lambda \approx 6 \cdot 10^4$); ESO Coudé Auxiliary Telescope (CAT) + Coudé Echelle Spectrograph (CES) Long Camera + CCD ($\lambda/\Delta\lambda = 10^5$); ESO CAT +

*) Based on observations collected at the European Southern Observatory, La Silla, Chile, and at the Observatoire de Haute-Provence, Saint-Michel-l'Observatoire, France

CES Long Camera + Reticon ($\lambda/\Delta\lambda = 10^5$); ESO CAT + CES Short Camera + CCD ($\lambda/\Delta\lambda = 6 \cdot 10^4$).

For most stars, observations were repeated at various phases, allowing one to get at least some idea of the variability.

The mean magnetic field modulus H was derived for each observation. It was diagnosed from the wavelength shift between the split components of Fe II λ 6149.258. The wavelengths of the components were whenever possible measured by fitting gaussians to them; in a few rare cases, the centre of gravity of the components was determined through direct integration (both methods are described in Paper II). The lower limit of detection of a magnetic field in the present study is of the order of 3 kG.

More can be diagnosed from the recorded spectra than just the value of the mean field modulus. Given the low noise of the data, exploitable information is contained in the shapes of the line profiles (of the split components, in particular). The full extraction of this information is not achieved yet, but the following qualitative result can already be pointed out. The two Fe II lines λ 6147.741 and λ 6149.258 are formed in a regime of partial Paschen-Back effect, and not of Zeeman effect (Paper I). Consequently, their splitting pattern is asymmetric. Therefore, in stars with negligible rotation, the blue component of the doublet Fe II λ 6149.258 is deeper and narrower than its red component. Departures from this behaviour are observed in a number of stars of the sample, at least at some phases. This indicates that the line profiles in these stars contain a detectable contribution of rotational Doppler effect, thus that these stars have $v_e \sin i$ significantly different from zero.

NOTES ON INDIVIDUAL STARS

Hereafter, a brief individual presentation of the stars considered in this study will be given. We indicate in parentheses, after the HD number of each star, its spectral type (from Renson *et al.* 1991) and the reference of the paper first reporting the detection of resolved magnetically split lines in its spectrum.

HD 2453 (A1p SrEuCr; Paper II) has a mean magnetic field modulus essentially constant (3.7 – 3.8 kG) over its rotation period of 546^d87 (Catalano & Leone 1990).

HD 9996 (B9p CrEuSi; Paper II): the difference between the two values of H (3.8 and 4.4 kG) that we derive from two observations separated by less than one year is remarkably large, considering that the period of this star is of the order of 21 years (Rice 1988). The split line components are furthermore unusually broad, pointing to an uncommon field geometry.

HD 12288 (A2p CrSi; Preston 1971) has been observed 5 times, yielding values of the field modulus ranging between 7.4 and 8.4 kG. Significant variations of H occur on timescales as short as 2 days, and significant rotational Doppler effect is seen in the line profiles. This indicates that the star should have a rather short rotation period, possibly shorter than the value of 34^d9 suggested by Wolf & Morrison (1973).

HD 14437 (B9p CrEuSi) is reported here for the first time to have resolved magnetically split lines. A portion of its spectrum containing the above-mentioned lines of Cr II and of Fe II is shown in Fig. 1. The profiles of these lines appear significantly affected by rotational Doppler effect. A

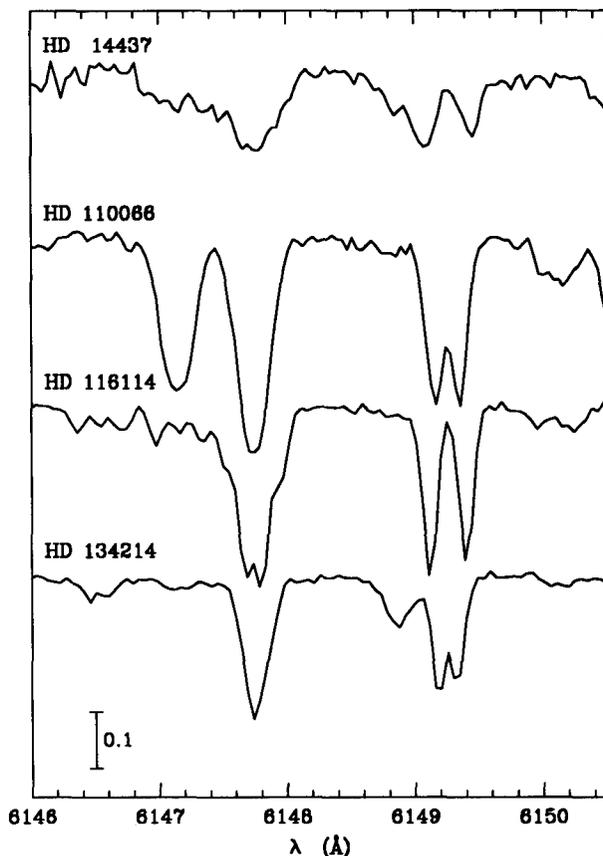


Fig. 1. Portion of the spectrum of the four newly discovered Ap stars with resolved Zeeman split lines reported in this paper, showing the region of the lines Cr II λ 6147.154, Fe II λ 6147.741, and Fe II λ 6149.258. The spectra are normalized to the continuum; the ordinate is shown by the bar at the bottom of the figure. Each spectrum is labelled with the HD number of the star.

field modulus of 7.9 kG is derived from two observations separated by about 100 days.

HD 18078 (A0p SrCr; Paper II): two markedly different values of the field modulus (3.3 and 4.4 kG) have been derived from two observations (470 days apart) of the star, whose period is probably longer than 1 year (Wolff & Morrison 1973).

HD 50169 (A3p SrCrEu; Paper II): we measured a field modulus of 4.4 kG from our only observation of this star, which has been reported to have H α emission (Brewer 1953).

HD 55719 (A3p SrCrEu; Paper I) has line profiles that seem to some extent affected by rotational Doppler effect, but that do not show large

variations. The six values of H that we have determined are all comprised between 6.1 and 6.4 kG.

HD 81009 (A3p CrSrSi; Preston 1971): though our seven observations of this star are concentrated in hardly more than one third of its rotation period (33^d96; Waelkens 1985), apparently about a minimum of the field, rather remarkable variations of both H (between 7.3 and 8.4 kG) and the line profiles are found.

HD 94660 (A0p EuCrSi; Paper I): we have obtained four observations of this star, over more than 1000 days. H is possibly slowly increasing monotonically from the first to the last of these observations (from 6.1 to 6.4 kG). The star may have a very long period.

HD 110066 (A1p SrCrEu): the observation of resolved magnetically split lines in this star is reported here for the first time. From the spectrum illustrated in Fig. 1, a mean field modulus of 4.1 kG was diagnosed, slightly larger than the field of 3.6 kG estimated by Preston (1971) through the analysis of differential line broadening.

HD 116114 (F0p SrCrEu) is another newly discovered star with resolved magnetically split lines. A portion of its spectrum is shown in Fig. 1. The value of H derived from this single observation is 5.9 kG.

HD 116458 (A0p SiEuCr; Paper I) shows no significant variation of H (4.6 – 4.7 kG) or of the line profiles between our three observations, which span a time interval of more than 1000 days.

HD 126515 (A2p SrCr; Preston 1970) is one of the four stars with resolved magnetically split lines that has been repeatedly observed throughout its rotation period (130 days; Preston 1970). The large amplitude of the variations of its mean field modulus (from 10 to 17 kG) is famous. Our observations show that the line component profiles also undergo remarkable variations.

HD 134214 (F2p SrEuCr): the resolution of magnetically split lines in the spectra of this star (illustrated in Fig. 1) is reported here for the first time. Our only observation yields a value of H of 3.2 kG.

HD 137909 (A9p SrEuCr; Preston 1969) is another of the four stars with resolved magnetically split lines for which observations have been obtained all over the rotation cycle. Its mean field modulus has been shown by Wolff & Wolff (1970) to vary between about 4.9 and 5.7 kG, with a period of 18^d4868 (Kurtz 1989). Our measurements of H agree well with the previous observations. Rotational Doppler effect is visible in the line profiles.

HD 137949 (F0p SrEuCr; Paper II): our two observations of this star, 4 days apart, show neither variations of H (4.9 kG) nor rotational Doppler effect, though the rotation period might be shorter than 1 month (Kurtz 1982).

HD 165474 (A7p SrCrEu; Preston 1971) has been observed twice, more than 800 days apart. The same value of H , 6.4 kG, is derived from the two spectra; this value is significantly smaller than that obtained by Preston (7.2 kG). Line profile variability cannot be safely assessed, because of a difference of resolution and of a definite change of the line intensities between our two spectra.

HD 187474 (A0p EuCrSi; Didelon 1987) has a mean field modulus probably varying with one maximum (≥ 6 kG) and one minimum (≤ 5 kG) per 2345 d (Mathys 1991) rotation period.

HD 188041 (A6p SrCrEu; Preston 1971): the mean field modulus of this star (3.6 – 3.7 kG) does not seem to show any significant variation over its

rotation period of about 224 days (Mathys 1991).

HD 192678 (A2p Cr; Paper II) shows definite short-term variability (detected over time-intervals as short as one day) of H (between 4.7 and 5.0 kG) and of the line profiles, which are significantly affected by rotational Doppler effect.

HD 200311 (B9p SiCrHg; Preston, cited by Adelman 1974): variations of H (between 9.0 and 9.6 kG) and of the line profiles occur in a few days in this star.

HD 201601 (A9p SrEu; Scholz 1979, confirmed in Paper I) is famous for its extreme long period, of the order of a century. H has slowly increased monotonically (from 3.7 to 4.0 kG) between our first and our last observations, which are separated by about 1200 days.

CONCLUSION

We have presented observational results about 22 Ap stars with resolved magnetically split lines (including 4 stars in which the resolution of the lines is reported for the first time). These results are still incomplete and preliminary. However, they already provide useful information about the magnetic field of the studied stars. A next step will be to achieve good phase coverage for the observations of as many stars as possible. This will, of course, be easier for stars that do not have extremely long periods. From the information available about their variations, or from the appearance of rotational Doppler effect in their line profiles, eight at least of the observed stars (HD 12288, HD 14437, HD 55719, HD 81009, HD 137909, HD 137949, HD 192678, and HD 200311) should have relatively short rotation periods (typically, of the order of one month or less).

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