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CLASSIFICATION OF Ap-STARS HR 830 AND 21 CVn

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КЛАССИФИКАЦИЯ Ар-ЗВЕЗД HR 830 И 21 CVn

Изучаются две неопределенно классифицированные звезды типа Ap HR 830 и 21 CVn. Наблюдательные данные сравниваются с данными для нормальных звезд αDel и αLyr. Звезда HR 830 классифицируется как Ap кремниевого типа на основании усиленного поглощения в линиях кремния, и переменности блеска в системе *UBV*. 21 CVn классифицируется как Ap кремниевого типа на основании ослабленных линий гелия, их переменности, фотометрической периодической переменности, и свойств UV спектра. Дается заключение, что фотометрическая периодическая переменность является хорошим индикатором свойств Ap быстро вращающихся A и поздних B звезд.

Two ambiguously classified Ap-stars, HR 830 and 21 CVn, are studied. The observational data are compared with the data for normal stars αDel and αLyr. The star HR 830 is classified as Ap of type Si based on the enhanced absorption in the Si lines and photometric variability in *UBV*. 21 CVn is classified as Ap Si based on weaker absorptions of helium, the variability of helium lines, photometric periodic variability and the properties of the UV spectrum. It is concluded that the photometric periodic variability is a good indicator of Ap-properties of rapidly rotating A and late B stars.

1. Introduction

Stars of spectral type A with insufficiently developed features of Ap-peculiarity, usually mentioned with ambiguous or uncertain classification, are interesting with regard to the possible elimination of the causes leading up to the generation of Ap-characteristics.

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Cowley et al. (1969) classified both the stars in this study as "A0 V — Si:" and in the catalogue of Bertaud and Floquet (1974) they are among the Ap-stars with an uncertain classification. The former study is based on low-dispersion spectrograms 12·5 nm mm^{-1} and the classification given means that "...silicon may be considerably enhanced but not enough for the star to be referred to as peculiar".

Spectroscopic studies founded on high-dispersion data nor systematic photometric observations have been published yet.

One UBV observation is given for HR 830 (HD 17 471, BD +24°396, $m_V = 5{\cdot}82$) in the catalogue of Blanco et al. (1968). Medium-band *uvbyβ* photometry was carried out by Johansen and Gyldenkerne (1970) and Philip et al. (1976). Their data do not indicate a photometric variability larger than about 0·01 mag, which is within the given values of the mean error for both sources.

UBV observations of 21 CVn (HR 5023, HD 115 735 BD + 50°1994, $m_V = 5{\cdot}15$) have been published by Blanco et al. (1968), Häggkvist and Oja (1966) and Häggkvist et al. (1971). In the individual papers the values of the B−V index differ by as much as 0·075 mag. Johansen and Gyldkerne (1970) and Philip et al. (1976) made observations in the *ubvyβ* system. The differences in the values of the $b-y$ indices are at limits of the given mean errors, 0·013 and 0·011 mag. According to narrow-band photometry in the K-line (Henry, 1969; Henry and Hesser, 1971) this star displays no variability up to an amplitude of 0·008 mag. UV fluxes in the interval 138−254 nm are published in the paper of Jamar et al. (1976).

In this paper we shall deal with the decisive features for the Ap-classification of the stars involved. Their spectral features are compared with the normal ones in the spectra of αDel and αLyr. The regions of lines Si II (1) in λ 385·4−386·3 nm and of Si II (3) in λ 412·8−413·1 and the helium line are studied. The effective temperatures and values of the surface gravity are derived from the photometry and Balmer line profiles.

2. Observations

Within the scope of our programme of studying Ap-stars with doubtful classification, we have included both stars in the lists for photometric and high-dispersion spectroscopic observations. The photometric observations were carried out with the 0·6*m* photometric reflector of the Astronomical Institute in Skalnaté Pleso. *UBV* observations for HR 830 were obtained on 9 nights. These *UBV* observations indicate variability within 0·04, 0·03 and 0·02 mag for *U*, *B* and *V* colours, however, they are not sufficient to determine periodicity if any. 21 VCn was observed on 13 nights by means of a medium-band filter with a central wavelength of 526 nm and halfwidth of 19 nm. Our medium-band photometry with the filter centred at 526 nm and a halfwidth of 19 nm disclosed a periodic variability with an amplitude of 0·04 mag and a period of 0·767 d.

The spectroscopic observations were made in the coude focus of the 2 m telescope of the Astronomical Institute in Ondřejov, the dispersion being 0·85 nm mm^{-1}, and in the National Astronomical Observatory of the Bulgarian Academy of Sciences in the coudé focus of their 2 m telescope with a dispersion of 0·9 nm mm^{-1}. For HR 830 we obtained 5 spectrograms with a dispersion of 0·85 nm mm^{-1}, IIaOb plates and 6 spectrograms with a dispersion of 0·9 nm mm^{-1}, plates IIaO. For 21 CVn we obtained 19 spectrograms with a dispersion of 0·85 nm mm^{-1}, plates IIaOb and 103aO. For αDel we had 3 and for αLyr 1 spectrogram with a dispersion of 0·85 nm mm^{-1}, plates IIaOb. The spectrograms were recorded with a microdensitometer with direct intensity recording (Minarovjech et al., 1983).

Table 1

Star	V	$B-V$	$U-B$	Source
HR 830	5·82	−0·07	−0·08	Blanco et al. (1968)
	5·89	+0·002	−0·125	Our photometry
21 CVn	5·15	0·00	−0·20	Blanco et al. (1968)
	5·15	−0·075		Häggkvist, Oja (196)
αDel	3·77	−0·06	−0·223	Blanco et al. (1968)

N.B.: If the referenced source mentions more than one observation, their average is given in this table.

Table 2

Star	$(b-y)_0$	c_0	m_0	$(u-b)_0$	β	θ	Ref
HR 830	−0·023	0·955	0·138	1·185	2·831	0·45	1
	−0·014	0·952	0·137		2·821		2
21 CVn	−0·024	0·945	0·135	1·167	2·842	0·45	1
	−0·037	0·939	0·144		2·844		2
αDel	−0·030	0·890	0·128	1·086	2·802	0·43	1
	−0·022	0·891	0·133		2·799		2

References: [1]) Phillip et al. (1976).
[2]) Johansen and Gyldenkerne (1970).

3. Effective Temperature and log *g*

3.1. *Photometry*

A number of studies has been published on the relation between the effective temperature and various photometric indices. A summarizing and exhaustive review is presented in Heintze's paper (1973) for the dependence of T_{eff} on the indices of *UBV* photometry. Equations 25a–c ($T_{eff} \sim U - B$) and 30a,b ($T_{eff} \sim$ $\sim Q$-parameter, spectral type) in the referenced paper were used to derive the effective temperatures of stars in the present study from available *UBV* data. To determine the effective temperature and surface gravity from the *uvby* we used the method described by Zabriskie (1977). The resultant mean values of T_{eff} and log g, together with their mean errors, are given in the first, second and sixth lines of Tab. 4. The eighth line of this table gives the spectral type determined from the average values of $(U - B)_0$ and $(B - V)_0$ indices after Allen (1977).

3.2. *Spectroscopy*

The shapes of the hydrogen lines are a good indicator of the effective temperature and, in the neighbourhood of spectral type AO, also of the value of log g. In our comparisons we have used the theoretical profiles of lines $H\beta$, $H\gamma$, $H\delta$ from the paper of Kurucz (1979). These theoretical profiles are normalized to unity (I_{cont}) at a distance of 10 nm from the centre of the line. Since it is impossible to observe the profiles practically to this distance in the spectrograms, we have normalized the theoretical profiles to unity separately for each spectrogram and line at the distance of the observed continuum, which was 3·5–5·0 nm from the centre of the line. Since the middle parts of the profiles of the hydrogen lines are affected by rotational broadening, we have estimated the value of $v \sin i$ from the halfwidth of the Mg II 448. 1 nm line, and with respect to it we have corrected the middle portions ($\Delta\lambda \leqq 0{\cdot}2$ nm) of the theoretical profiles. The values of the projected rotational velocity, $v \sin i$, determined after Slettebak et al. (1975), are given in Tab. 3. The resultant effective temperatures and log g, derived from the comparison of the $H\beta$-, $H\gamma$- and $H\delta$-curves, are in the third and seventh lines of Tab. 4.

Table 3

Star	HW nm	$v \sin i$ km s^{-1}	n
HR 830	0·144 ± 0·004	59 ± 8	8
21 CVn	0·225 0·005	91 8	12
αDel	0·322 0·004	129 8	3

Table 4

	HR 830	21 CVn	αDel	Notes
T_{eff} [K]	10 850 ± 140	11 260 ± 120	11 710 ± 190	*UBV*
	10 920 140	10 890 155	11 420 150	*uvby β*
	10 890 100	11 360 130	11 920 95	*β, γ, δ*
	5	5	3	a
	11	14	9	b
log g	4·09 ± 0·03	4·18 ± 0·03	4·12 ± 0·04	*uvbyβ*
	3·92 0·03	4·0	3·91 0·04	*β, γ, δ*
Spektrum	B 9	B 8·5	B 8	*UBV*
	A 0 V	A 0 V	B 9 V	*c*

a) number of plates used
b) number of measured profiles
c) Cowley et al. (1969)

4. Spectrum Ap-Classification

4.1. *High-Dispersion Features*

The lines of ionized silicon Si II (1) λ 385·4–386·3 nm and Si II (3) λ 412·8–413·1 nm are indicators of peculiarity. According to Cowley et al. (1969), the lines of multiplet 3 are considerably enhanced in both stars. By comparing them with the spectra of the normal stars αDel (B 9 V, Cowley et al., 1969) and αLyr (A0V) we can determine to what degree they have been enhanced. At the observed rotational velocities particularly 21 CVn and αDel (91 and 129 km/s) display considerably broadened lines, so that mutual overlapping and blending with other lines, in this case with Eu II and FeI, do not allow the equivalent widths to be measured separately. Consequently, we measured the whole "equivalent width" of the absorption formation within the limits of the wavelengths given by the positions of the marginal lines and the rotational width for the most rapid rotation (αDel). As regards Si II (3) this involved the section λ 412·62–413·36 nm with the assumed marginal lines Si II (3) λ 412·81 and Fe I 43 λ 413·21 nm and, as regards Si II (1) this involved the section λ 385·37 and Fe I 20 λ 386·55 nm. Table 5 summarizes the results of absorption measurements, expressed in terms of the equivalent width in nm. The errors are mean square and their higher values do not indicate absorption variability but rather different signal-to-noise ratios which varies from ≈0·05 units of continuum intensity in the better spectrograms to ≈0·1 in the worse. In our measurements we integrated the actual spectrum record to avoid introducing a subjective deviation in determining the shape of complicated curves. The signal-to-noise ratio depends, to some extent, on the procedure of processing the plates and is more important in the region of Si II (1) where the photographic density decreases as a result of the overlapping of the wings of lines H 8 and H 9. The equivalent widths of the helium lines at λ 447·2 and 414·4 nm were measured separately with smoothed curves.

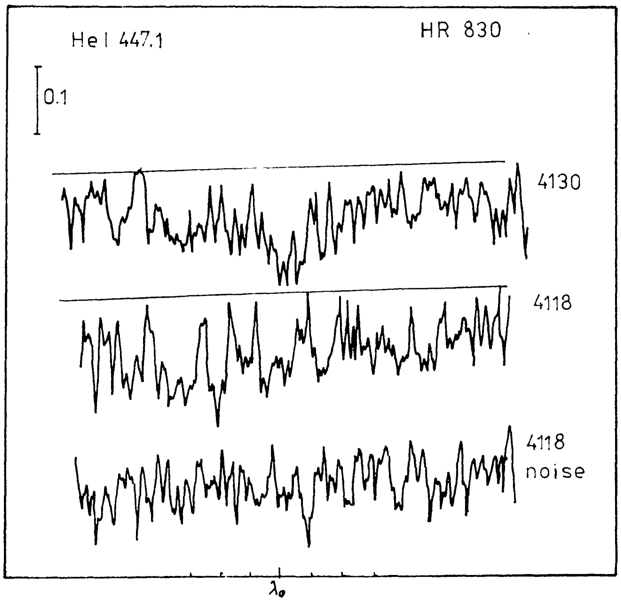

Fig. 1. HR 830: intensity record of the He I 447·2 nm line region.

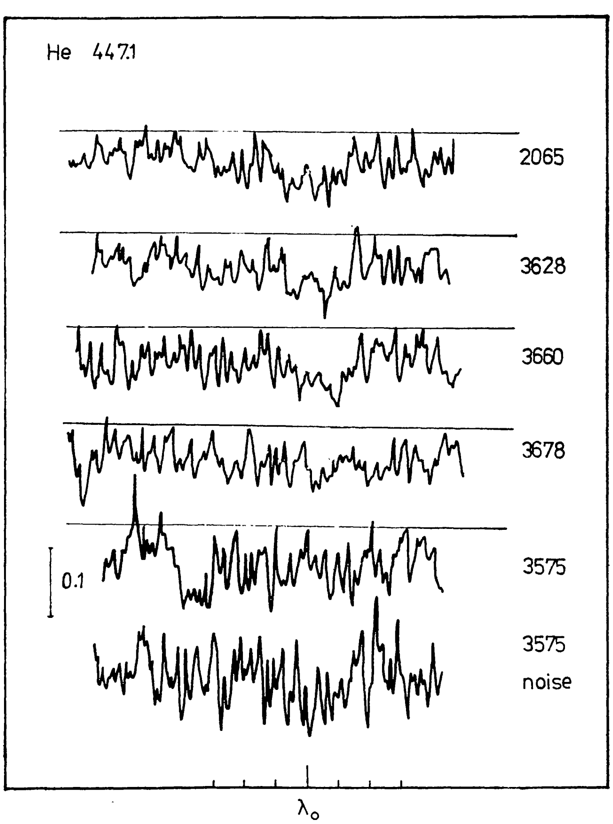

Fig. 2. 21 CVn: intensity record of the He I 447·2 nm line region.

In HR 830 the variability of absorption lines of silicon was not observed and the variability of helium lines is disputable. The plates with a more advantageous signal-to-noise ratio show line λ 447·2 nm clearly, this aplies to plate No. 4130, whereas if the ratio is worse, this applies to plate No. 4118, the shape of the line is disrupted considerably, Fig. 1.

In 21 CVn the intensity of the helium lines seems to vary. For example, line λ 447·2 nm can be seen clearly on plates Nos 3660, 2065 and 3628, whereas on plate No. 3678 it is obscured by noise and on No. 3575 it cannot be seen at all, Fig. 2.

4.2. *UV Spectrum*

Stars 21 CVn and αDel were observed in the UV region of the spectrum with a spectrometer located on board the TD-1 satellite. The results of measuring fluxes in the spectral region $\lambda\lambda$ 138 – 254 nm have been published by Jamar et al. (1976) in the "UV Bright-Star Spectrophotometric Catalogue". The UV spectra of 77 Ap-stars from this catalogue, selected on the basis of an earlier classification (Bertaud and Floquet, 1974), were analysed by Jamar et al. (1978), but 21 CVn was not included in this set because its classification was ambiguous. Nor was this star recognized as an Ap-star in testing the UV fluxes according to the δ_{1400} parameter.

The comparison of the UV continua of 21 CVn and αDel clearly indicate a smaller slope of the spectrum of the former below 200 nm, Fig. 3. This may partly be due to the effective temperature being 500 K lower than that of the comparison star, however, the shape of the spectrum of 21 CVn indicates that absorptions have affected it more than the spec-

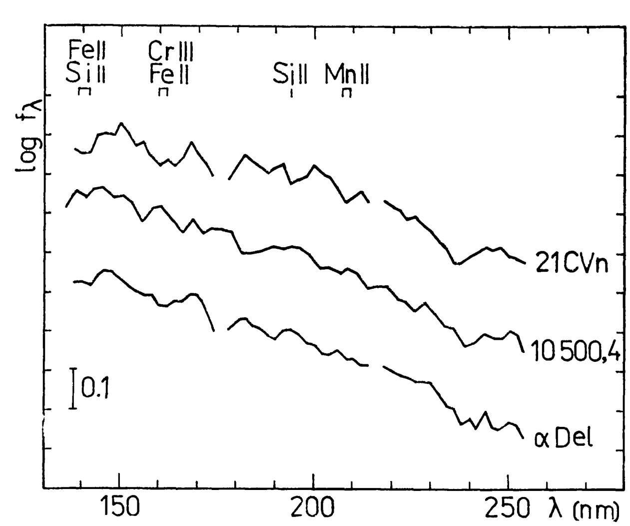

Fig. 3. Comparison of UV spectra of αDel, 21 CVn (after Jamar et al., 1976, corrected for reddening) and of the theoretical (after Kurucz, 1979).

Table 5

Absorption in the Si II and He I lines in nm

	Si II 1 λ 385·3–6·4	Si II 3 λ 412·8–3·1	He I 14 λ 447·2	He I 53 λ 414·4	Sp. *UBV*
HR 830	0·140	0·084	0·022	0·013	B 9
	± 8	4	2		
	$n=$ 6	8	5	1	
21 CVn	0·102	0·047	0·014	0·008	B 8·5
	± 6	1	1	1	
	$n=$ 10	13	9	4	
αDel	0·085	0·057	0·023	0·024	B 8
	± 4	6	1	1	
	$n=$ 3	3	3	3	
αLyr	0·077	0·021	0·005	0·005	A 0
	$n=$ 1	1	1	1	

$n=$ Number of plates measured

trum of the normal star αDel. First of all, the absorption at λ 140 nm, caused by Fe II and by self-ionization of Si II, is quite clear (Jamar et al., 1978), accompanied by absorption at λ 194 nm. Also the absorption due to Fe II and Cr III (?) at λ 160 nm is greater than in αDel. The decrease of the continuum at λ 208 nm, probably due to Mn II, is remarkable. It is indeed this absorption which could have been responsible for 21 CVn being missed in testing the spectra of Ap peculiarity by means of the δ_{1400} parameter which is based on comparing the λ 140 nm and 210 nm fluxes.

5. Discussion

The results of the measurements, summarized in Tab. 5, indicate that the absorption in the silicon lines in the spectrum of HR 830 is higher by 50–60% than normal. The absorption in the helium lines is normal for the spectral type determined by *UBV*. The variability of the helium lines is questionable, but the photometric variability in *UBV* of a few hundredths of magnitude and the dependence of the amplitude on wavelength, proved by our observations, are typical of Ap-stars. These properties are characteristic of Ap-stars and, therefore, HR 830 may be classified as Ap with an Si-type peculiarity.

As regards 21 VCn, the absorption in Si II (3) is comparable with the value determined for αDel. Nor does the criterium in Si II (1) indicate a significant overabundance of absorption as compared to normal. The situation is different, however, in the helium lines. According to the spectral type determined from *UBV* photometry, the intensity of the helium absorption should be between the values for αDel (B 8) and HR 830 (B 9). However, it is actually weaker and rather corresponds to spectral type B 9·5, between HR 830 and αLyr. This helium deficiency in 21 CVn is evidence in favour of the Ap-classification, which also applies to the photometric periodicity of the 0·04 mag variability with a period of 0·767 d, observed in our photometry.

The medium-band *ubvyβ* photometry yields a metallic index "m_1" which represents the degree of enhanced absorption by metal lines in the violet part of the spectrum. In the c–m diagrams (Cameron, 1966) both the stars are in a region with normal and Ap-stars. These criteria cannot, therefore, be used to decide whether 21 CVn and HR 830 are Ap-stars. Since the other criteria indicate Ap-peculiarity, these two stars should be considered "low-m" Ap-stars.

The analysis of 21 CVn observations yields an important result for the relation between slow rotation and the Ap-characteristics. The relatively high value of $v \sin i$ (in this particular case 91 km/s) cancels, to a large extent, the intensification of the individual absorptions. At high dispersion the lines may overlap and become shallow, so that enhanced absorption need not be determined by measurement as regards problems with continuum drawing and the effect of noise. At low dispersions the intensification is degraded. However, if an Ap-star is really involved, which may display photometric variability due to the distribution of elements on its surface, as opposed to the shapes of the lines, it is not affected even by more rapid rotation. Photometric variability, as in the case of 21 CVn, remains undegraded. It follows that slow rotation is not a condition for the creation of Ap-properties. It is rather an equivalent, more or less developed property and aids in the spectroscopic detection of Ap-stars by not smudging the intensified absorption. The photometric periodic variability of A (and late B) stars is thus a good indicator of Ap (Bp) properties, provided cannot be determined uniquely by spectroscopy.

6. Conclusions

By analysing high-dispersion spectrograms, UV observations and photometric results, we have shown that stars HR 830 and 21 CVn may be classified as Ap (Bp) stars. As regards HR 830 this classification is justified by the absorption in the silicon lines, enhanced by 50–60% as compared to normal, and by photometric variability of 0·04, 0·03 and 0·02 mag in U, B and V colours. The variability of the helium line at λ 447·2 nm, although it has not been definitely proved, is possible. 21 CVn does not have significantly enhanced silicon absorptions, which may be obscured by the high rotational velocity of the star. However, the helium line absorption corresponds to the later spectral type and is variable. Another Ap-property is the periodic photometric variability of 0·04 mag in the filter centred at 526 nm with a halfwidth of 19 nm. The UV spectrum of this star has more absorptions than the normal αDel.

Based on the observational data of 21 CVn, it is concluded that slow rotation is not one of the conditions for creating Ap-properties (to allow for the stability of the atmosphere on creating the height and surface distribution of elements). The enhanced absorptions in the spectrum may be smudged by high rotational velocity which, in combination with the uncertainty in continuum drawing, leads to their obscuration on high-dispersion spectrograms and to degradation in low-dispersion spectrograms. Rapid rotation cannot degrade or obscure photometric periodic variability caused by non-uniform distribution of elements over the star's surface. It can, therefore be seen well and can serve as a criterion for determining Ap (late Bp) stars.

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