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The frequency of Ap-stars with long rotation periods*

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Summary: We observed light variability over time intervals of months to years in the stars HD 55540, HD 71066, HD 94660, and HD 187474. We discuss the significance of these results in terms of the frequency of chemically peculiar CP2 stars showing (light) variability with periods longer than one month. This frequency, relative to the whole CP2 population, must lie somewhere between 4 and 16%. Observations, properly distributed in time, of a small subgroup of CP2 stars will be sufficient to obtain an accurate ratio n_{LP}/n_{tot}. These observations, when continued until the periodicity is detected, could contribute also to the discussion whether these long periods should be identified with the rotation period.

Key words: Ap-stars – photometric variability – long periods

Introduction

Ap stars and in particular CP2 stars (following the terminology introduced by Preston, 1974) often show spectroscopic, magnetic and photometric variations which obey the same periodicity. In general, these variations are interpreted in the framework of the oblique rotator model and the derived period is identified as the rotation period of the star. Rotation periods of less than two weeks are usually determined by photometrists, apparently because this kind of observations may be collected fast in one or two observing runs of ordinary length. However, many photometrists do not have the opportunity to observe a star during longer time intervals. Apparently, it has been easier for spectroscopists to monitor Ap-stars over longer time intervals, since longer Ap-periods have been found dominantly by spectroscopic studies (e.g. Babcock, 1954; Preston, 1970a; Preston and Wolff, 1970). In some cases they were confirmed by photometry afterwards. To our knowledge, the only discussion of photometric variations over periods of years was presented by Wolff (1975) and Wolff and Morrison (1973). Their investigation has been based on a list of sharp-lined Ap-stars published by Preston (1970b). Altogether nine periods with lengths up to 1.5 yr were determined unambiguously, including only one case with P less than 10 d. No effort was done to cover longer periods. The possibility of variations over longer time intervals was discussed by comparing their absolute photometry to that obtained in earlier analyses.

It is our aim to describe in this paper the first results of an observational program performed mainly at ESO to find out whether the frequency of CP2 stars with long photometric periods (LP stars) might be largely underestimated at present. It is evident from the manner in which the observational data have been collected in the past, that there may be a large observational bias leading to an underestimation of the frequency of LP stars. The necessary condition for detection of LP stars has been more or less the existence of pronounced variability of spectral lines, either in strength or by variable Zeeman displacements. If we would apply the same condition to the faster rotating Ap-stars, we would miss most of them. Thus, the observational bias in favour of faster rotators would disappear only if pronounced stellar variability would be coupled a priori with slow rotation or if photometric variability with periods longer than one month would never be due to stellar rotation. After presenting our observational results, we will summarize our knowledge on LP stars and we will discuss the frequency of very slowly rotating CP2 stars. Finally, we present a list of CP2 stars that are good candidate LP stars (although some of them certainly will turn out to be photometrically constant) and we suggest comparison stars to be used in photometric variability studies.

Photometry of some apparently constant CP2 stars

In previous runs, before 1979, we observed a number of Ap stars that did not show appreciable variability during the concerning run(s) (less than 0.01 mag). When we decided to combine our observational effort in the European Ap Working Group, four of these stars were chosen to be observed in any suitable run in order to check their constancy in longer time intervals. Moreover, HD 187474 was added to check the proposed 6.7 yr period.

The aim of this project was to investigate whether the large majority of stars found to be constant during typically ten nights would turn out to be intrinsically constant, with a minimum of observing time. Therefore, we gave preference in our selection to the best candidates for rejecting this hypothesis. Stars with a strong λ 5200-feature with enhanced line strengths of Sr, Cr or Eu

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* Based to a large extent on observations collected at the European Southern Observatory (ESO), La Silla, Chile

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Table 1. Observed variability in Ap stars

HD (Ap)	1st comp. 2nd comp.	Observing runs	n (nights)	Range (mag)	Sigma (mag)	Rel. sigma
52847	52190 53433	(3)*, (4)*, (9)*, (10)*, (17)	13	<0.015 all	<0.007 all	–
55540	55816 55521	(3)*, (4)*, (9)*, (10), (13), (16), (17)	15	0.044u	0.017u	1.5y 1.1b 1.5v 2.4u
71066	71576 76270	(1), (7)*, (9) (13), (17), (19)[b]	17	0.035y 0.040b 0.034v 0.038u	0.014y 0.016b 0.013v 0.024u	6.1y 6.6b 3.8v 1.2u[a]
94660	94724 93453	(6), (7), (8), (11), (13), (14), (15), (17), (18)	38	0.053v 0.087u	0.017v 0.031u	2.0y 1.2b 4.5v 6.1u
187474	189388 189079	(2)*, (5)*, (12), (15), (16), (18), (19)	25	0.041y 0.062b 0.047v 0.043u	0.018y 0.029b 0.020v 0.016u	3.7y 6.6b 3.7v 2.9u

[a] HD 76270 is suspected to be slightly variable in u (0.03 mag)
[b] Only Strömgren u and v were observed

Notes:

Column 2: HD-numbers of the comparison stars used
Column 3: reference to observing runs as listed below. An asterisk after the run number indicates that only the first comparison star was used.
Column 4: Total number of nights on which the observations were made.
Column 5: magnitude range and respective filter, but only if the range of the Ap-star in the concerning filter is 0.03 mag or larger.
Column 6: scatter of the individual differential measurements Ap minus comparison star (standard deviation of average value in each run) in case the magnitude range is mentioned.
Column 7: sigma (Ap-comp.) in units of sigma (comp. 1–comp. 2) for each filter.

The observing runs are labelled as follows:

(1) Olsen, E.H.: Dec. 71/Jan. 72 — ESO Dan. 50 cm telescope
(2) Olsen, E.H.: June 1972 — ESO Dan. 50 cm
(3) Maitzen, H.M.: Feb. 1973 — ESO 1 m
(4) Maitzen, H.M.: March 1974 — ESO Bochum 61 cm
(5) Maitzen, H.M.: Oct. 1974 — ESO Bochum 61 cm
(6) Heck, A., Manfroid, J.: Feb. 75 — ESO Dan. 50 cm
(7) Heck, A.: Dec. 1975 — ESO 50 cm
(8) Manfroid, J.: Jan. 1977 — ESO Dan. 50 cm
(9) Maitzen, H.M.: Nov. 1979 — ESO 50 cm
(10) Hensberge, H.: Dec. 1979 — ESO 50 cm
(11) Doom, C.: March 1980 — ESO Dan. 50 cm
(12) Floquet, M.: July 1980 — ESO 50 cm
(13) Catalano, F.A.: Jan. 1981 — ESO 50 cm
(14) Weiss, W.W.: March 1981 — ESO 50 cm
(15) Schneider, H.: May 1981 — ESO 50 cm
(16) Manfroid, J.: Sep. 1981 — ESO Dan. 50 cm
(17) Manfroid, J.: Jan. 1982 — ESO Dan. 50 cm
(18) Schneider, H.: June 1982 — ESO 50 cm
(19) Maitzen, H.M.: Oct./Nov. 82 — CTIO 1 m Yale

Runs (3) to (7) were not used in calculating range and sigma, in order to exclude any contribution from uncertain transformation to standard system.

were considered to have larger probability of showing variability over longer time intervals, as judged from existing observational evidence. HD 52847 and, to a lesser extent since they are in the domain $b-y<o$, HD 55540 and HD 94660 appeared appropriate. In addition, we included the apparently constant, but low Δa (=weak λ5200) star HD 71066 because of its similar right ascension. Thus, our sample should not be considered as random in the population of sharp-lined apparently photometric constant stars. They tend to have larger Δa than average for given $b-y$ (statistically favouring longer periods?), but are bluer as a group than the known long period stars (statistically against long periods?).

Our results, summarized in Table 1, prove that all stars but HD 52847 are definitely variable. Therefore, we conclude that:

a) stars with longer photometric periods are systematically overlooked;

b) stars with long photometric periods appear over a larger color interval than established previously (HD 94660 has $b-y=-0.09$);

c) stars with long photometric periods may have weak λ5200-feature (HD 71066).

We do not list all our observations in detail, because in general they are not sufficient to discuss the periodicity and because part of them are already given in Hensberge et al. (1981). All details are available, however, and may be obtained from the first author.

Yet, two stars deserve some further discussion.

Our photometry of HD 187474 might be compared to the proposed 6.7 yr period. Unfortunately, the spectroscopic material on which this period relies is unpublished and the only reference to it is in the citation of Babcock's result by Wolff (1975). Neither the reliability, nor the accuracy are known.

We lack measurements over half of the period (Fig. 1). However, the variability itself is well established. The variations appear to be *roughly* in phase, but differences in the shape of the variations at different wavelengths are already apparent. The λ5200-feature is strong and much more variable than commonly observed in Ap-stars. The only information on magnetic field strength is from Babcock's measurements $H_e=-1.9$ kG during June 12–October 8, 1957 (Babcock, 1958). These measurements correspond to phase 0.55–0.60 in our Fig. 1, a phase that will be observable again in 1984. If Δa varies in phase with the magnetic field as is observed in HD 126515 (European ApWG, unpublished) and as is expected from the correlation between Δa and $\mathbf{H}_e$ (corresponding to the Geneva $Z-H_e$ relation, see Cramer and Maeder, 1980) then Babcock's measurements very likely do not correspond to the maximum observable effective field. Our photometry suggests that the largest absolute value of the effective field might correspond to phase 0.05. Therefore, magnetic field observations obtained in 1986–87 would be of high value, both to have an idea of extreme effective field strength and to see whether a polarity reversal occurs in HD 187474.

HD 94660 was observed in our project at eight well separated epochs; in addition, earlier differential observations with at least one comparison star in common could be recovered at three other epochs. Borra and Landstreet (1975) obtained for this star an effective field strength $H_e=-3.3$ kG. The repeatedly observed constancy over 10 d intervals, in contrast with the obvious variability on a time scale of the order of years, points to periods in excess of 100 d. On the other hand, the observed decline in u from maximum to minimum observed light in 70 d only, makes it very unlikely that the correct period is longer than two years. Variations in y and b, if present at all, do not exceed 0.01 mag; only v and u contain significant information for a period search. The number of epochs is low enough for period search methods to give spurious results.

Therefore, the observing campaign on this star is being continued to enable the reliable determination of its rotation period.

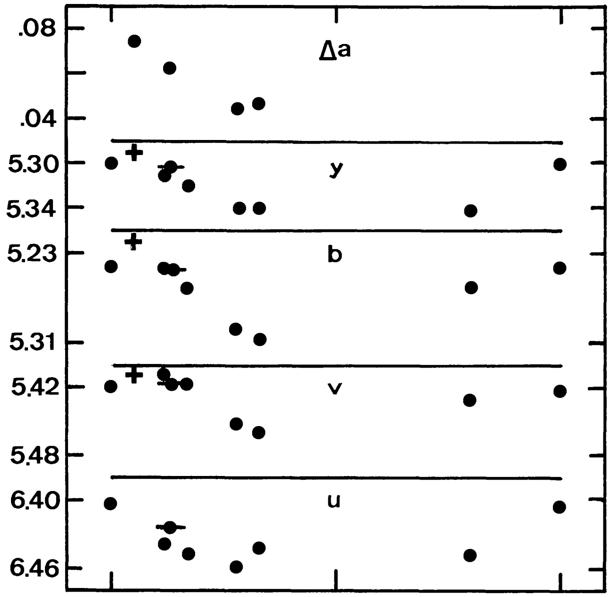

Fig. 1. The light variability of HD 187474 plotted according to the ephemeris JD (phase zero) $=2444457.77+2450$ E. The ordinate has been fixed by taking $y=6.314$, $b-y=0.055$, $m_1=0.189$, $c_1=1.026$ for the comparison star HD 189388. Phase zero has been chosen arbitrarily. Different symbols are used to indicate the differential measurement of run (5) (notation see Table 1) because a small systematic difference might exist due to uncertainty in the transformation to the standard system (-●-), and to indicate the absolute measurement of Maitzen in March/April 1974 (+). Each symbol refers to a different observing run and represents in most cases the average value of several measurements obtained during one or two weeks. Those averaged individual measurements were checked explicitly to be consistent within the measuring accuracy

The frequency of LP-CP2 stars

In this section, we will discuss the number of LP-CP2 stars, n_{LP}, relative to the total number of CP2 stars, n_{tot}. The discussion will mainly apply to an apparent-magnitude-limited sample, but, eventually, the extrapolation to the whole class of CP2 stars is considered.

We have searched the literature of CP2 stars brighter than $m_v=6.5$ for photometric, spectroscopic or magnetic periods and for $v\sin i$ values. Each star has been assigned to one of the four groups SP, LP, C or U defined in Table 2. It is clear that the C- and U-group contain as well short-period as long-period stars.

As a result of the definition of the groups, the fraction of LP stars in the C and U groups must be higher than in the total sample. Indeed, constant short-period stars with known $v\sin i$ larger than 30 km s^{-1} and stars with unknown period but $v\sin i$ larger than 30 km s^{-1} have been classified in the SP group rather than in group C or U. Thus, $n(\mathrm{LP})/[n(\mathrm{LP})+n(\mathrm{SP})]\doteq 3.5\%$ is a lower limit for $n_{\mathrm{LP}}/n_{\mathrm{tot}}$ in an apparent magnitude limited sample.

In order to obtain a reasonable upper limit, we will estimate the number of LP stars hidden in the U-group. It consists of stars

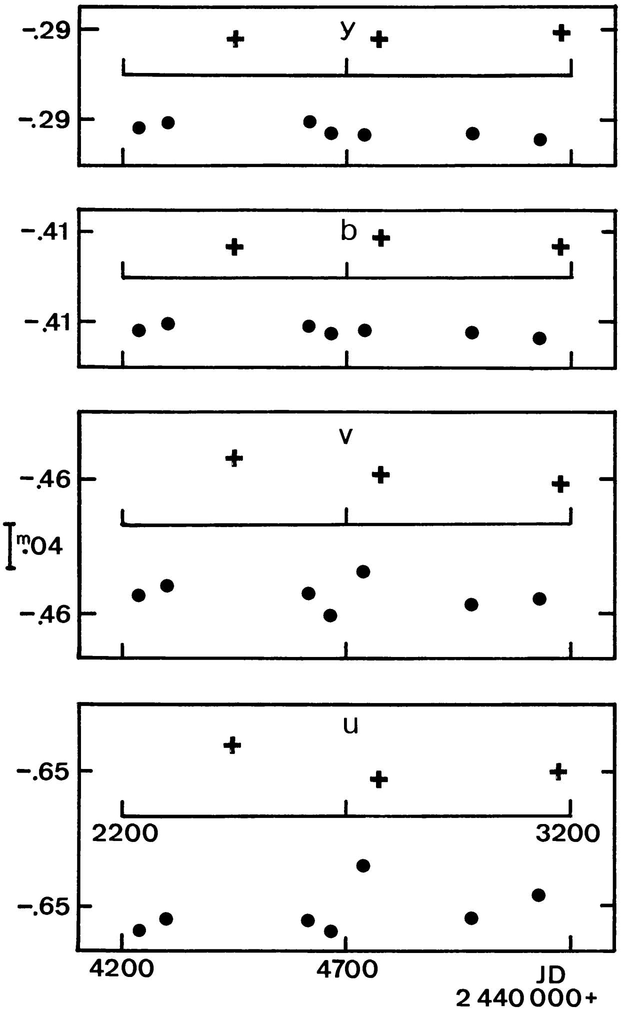

Fig. 2. The light variability of HD 94660 plotted versus Julian date. Magnitude differences are in the sense HD 94660 minus HD 94724. Crosses indicate numerous observations at constant level during one week. The Julian Date marks are given only for the *u*-plot, but apply to the other colors as well. Brightness increases to the top, the scale of the ordinates is given at left

unobserved for variability *and* $v \sin i$ (subgroup Uu) and of known apparently slow rotators unobserved for variability (subgroup Un). In subgroup Uu we expect no observational bias with respect to rotation period. For Un, we estimate

$$n_{LP}(\mathrm{Un})/n(\mathrm{Un}) = n_{LP}/n_{(v\sin i<30\,\mathrm{km\,s^{-1}})}$$
$$= [n_{LP}/n_{tot}]\,[n_{tot}/n_{(v\sin i<30\,\mathrm{km\,s^{-1}})}]$$
$$= 3\,n_{LP}/n_{tot}\,.$$

The numerical factor 3 has been obtained from the distribution of rotation velocities in the subgroup of stars with known $v \sin i$ in our sample.

Thus, expressing that all stars in group C might be LP stars and using our estimate of LP stars hidden in group U:

$$n_{LP}/n_{tot} < [n(\mathrm{LP}) + n(\mathrm{C}) + (n_{LP}/n_{tot}) \times (n(\mathrm{Uu}) + 3n(\mathrm{Un}))]/n(\mathrm{tot})$$

or

$$n_{LP}/n_{tot} < [n(\mathrm{LP}) + n(\mathrm{C})]/[n(\mathrm{tot}) - n(\mathrm{Uu}) - 3n(\mathrm{Un})] = 0.13$$

Table 2.

Group design.	Group definition	Criteria
SP	Short period CP2 stars	Well-determined periods shorter than 30 d Well-defined variability over intervals of few days. Rotational broadened lines $v \sin i > 30\,\mathrm{km\,s^{-1}}$.
LP	Long period CP2 stars	Well-determined periods longer than 30 d. Sharp-lined stars showing over months or years well established much larger variability than in time intervals up to one week.
C	Apparently constant, possible LP stars	No definite variability during (photometric) monitoring of at least one week *and* $v \sin i < 30\,\mathrm{km\,s^{-1}}$ or unknown.
U	"Unobserved" CP2 stars	Stars that cannot be assigned yet to one of the previous groups by lack of discriminative data.

Table 3. Statistics on bright CP2-stars. (See text for explanation of symbols)

Group	n (group) =	n (group, Si) +	n (group, non-Si)
SP	170	116	54
LP	6	3	3
C	15	8	7
U	39	28	11
Uu	26	21	5
Un	13	7	6
Total	230	155	75

So,
$0.035 < n_{LP}/n_{tot} < 0.13$
as can be seen from Table 3.

The precise value depends critically on the unknown number of LP stars in group C.

Without additional observations of the stars in group C (checks on $v \sin i$ followed by variability studies for the apparently slow rotators), the frequency of long period stars remains uncertain by a factor of 4. We intend to observe the stars in group C regularly in Strömgren photometry (in fact, the southern stars are monitored at ESO from October 1982 on, the northern stars at Catania from 1984 on). A list of these stars is given in Table 4 together with the comparison stars which are used.

An indirect argument for the presence of LP stars in group C is given by Δa and $\Delta(V1-G)$ photometry. Maitzen (1976) noticed that strong λ 5200-features are statistically correlated with slower rotation, and Hauck and North (1982) confirmed this trend from their Geneva photometry. This is corroborated by the larger mean $\Delta(V1-G)$ in the LP group, +0.021, as compared to the mean

$\Delta(V1-G)$ for six stars in the SP group showing no variability, $+0.002$ (nevertheless, both $\Delta(V1-G)$ distributions overlap and the criterion cannot be used to discern LP and SP stars).

Figure 3 shows the position in a $\Delta(V1-G)$, spectral type-diagram of stars in our group C relative to known LP and known constant SP stars. We notice that no intrinsically constant SP stars are known that have strong Europium lines, and that the larger $\Delta(V1-G)$ in the LP- (and C-) group is largely due to the contribution of stars with strong Europium lines. HD 110066, already noticed by Babcock (1958) to have exceedingly sharp lines and classified by Wolff (1975) as a star with a photometric period of several years on the basis of absolute photometry arguments, and HD 116458 are good candidate LP stars, in view of their large $\Delta(V1-G)$ and their classification. The "SrEuCr" classification also suggests slow rotation for HD 221760. This star might have a photometric period of 12,5 days following Van Genderen (1971), but we considered this result as too dubious because of the limited number of observations and the variability range of 0.005 mag and less.

Finally, we like to emphasize that the ultimate frequency of LP stars in the whole population of CP2 stars is higher than the frequency in our apparent-magnitude-limited sample. The construction of our sample implies that we gather the intrinsically brighter (Silicon) CP2 stars up to a larger distance than the cooler CP2 stars. Although LP stars appear over a large color range, they seem to tend (see Table 3) to the cooler end.

In order to estimate the mean absolute visual magnitude difference between Silicon and non-Silicon stars we make use of the survey of southern Ap-stars by Bidelman and MacConnell (1973). A subsample of this – all stars with $m_v \leqq 8.6$ – had been used by Maitzen and Vogt (1983) for deriving a mean absolute visual magnitude ($M_v=0.5$) for the Silicon stars by comparing the cumulative star counts in the 3rd and 4th galactic quadrants. This was possible because the distribution of extinction in both quadrants is radically different.

In the present work we considered the whole sample of Bidelman and MacConnell. We found an indication that a similar differentiation in the shape of the cumulative star count curves as found for the Silicon stars between the 3rd and 4th quadrant appears also for the non-Silicon stars but at an apparent magnitude which is 1.0 mag fainter (uncertainty ± 0.2 mag).

Thus, assuming a mean absolute visual magnitude difference of 1.0 ± 0.2 mag between both groups and assuming that the observed difference in LP frequency for both groups is real and not caused by chance or observational selection, we may calculate

$$0.045 < N_{\mathrm{LP}}/N_{\mathrm{tot}} < 0.16,$$

where N refers to a space limited sample.

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H.H. thanks E.H. Olsen for making available the necessary details concerning his individual absolute measurements for stars discussed in this paper. These data enabled us to calculate differential values whenever our comparison star and the Ap star were measured within 15 min.

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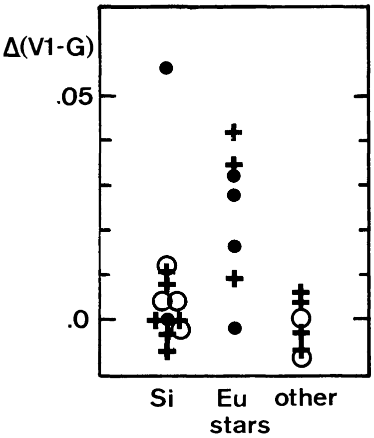

Fig. 3. Strength of the λ 5200 feature as measured by the Geneva $\Delta(V1-G)$ index vs. spectral peculiarity for three groups of stars: LP stars (*dots*); photometrically constant SP stars (*circles*); and stars of group C (*crosses*)

Table 4

CP2 star	Classif.	Comparison stars + spectral type	
HD 315	Si	HD 224945 (A3)	HD 294 (A0)
HD 3326	Sr	HD 4247 (F2)	HD 4772 (A3)
HD 38104	Cr	HD 39551 (A5)	HD 38179 (B9)
HD 50204	Si	HD 49344 (B9)	HD 48272 (A2)
HD 59256	Si	HD 60863 (B8)	HD 61672 (B7)
HD 77350	Si	HD 77557 (A1)	HD 79248 (A2)
HD 89822	Mg	HD 88983 (A8)	HD 90745 (A7)
HD 110066	Sr Cr Eu	HD 110787 (A3)	HD 112171 (A7)
HD 116458	Sr Eu	HD 116579 (B9)	HD 115967 (B6)
HD 137389	Si	HD 138406 (A0)	HD 138245 (A5)
HD 148330	Si Sr	HD 145674 (A1)	HD 148281 (A0)
HD 151771	Si	HD 153072 (A3)	HD 151726 (B9)
HD 191984	Sr Cr	HD 191709 (F0)	HD 188350 (A0)
HD 204411	Cr Si	HD 205314 (A0)	HD 203245 (B6)
HD 221760	Sr Cr Eu	HD 222095 (A2)	HD 223011 (A2)

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