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# Photometry of the Ap-Star HD 124224

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**Summary.** HD 124224 has been observed for light variations in the Strömgren system and with a spectrum scanner in the 3500 Å to 4600 Å region. The light curves are asymmetric and show different phases of maximum, depending on the colors. Some evidence could be found for short time fluctuations in H$\beta$. $\Theta$ seems to change from 0.375 to 0.360 and log$g$ from 3.60 to 3.45 (phase of light minimum to phase of maximum).

**Key words:** Ap-star – variable star – stellar atmosphere

## Introduction

Of all the known spectrum variable and peculiar A stars, HD 124224 (HR 5313, CU Vir, +3°2867, ADS 9152A) shows the shortest period in light and spectrum variations. A. Deutsch (1952) suggested that this periodicity is due to the rotation of the star according to an oblique rotator model. He also found a period of $P = 0^{\rm d}52067$.

B. Peterson (1966) confirmed Deutsch's observations that He I maximum coincides with the temperature minimum determined from $(B-V)$ and H$\gamma$-profiles, and with the minimum in $V$ and Si II. The variations of the Si II lines, differing in excitation potential by 2.7 eV, are slightly different, but have essentially the same phase. Further extensive spectroscopic studies have been published by Khoklova (1970). From Si II line variations, she derived a temperature range of $\Delta T \sim 1000$ K with a mean effective temperature of 13000 K. In a later paper (Khoklova, 1972), she discussed the influence of a Helium abundance anomaly on the composition of the atmosphere of HD 124224.

C. Blanco and F. Catalano (1971) improved the period using *UBV* observations and published the following elements for the light variation. We have adopted them for all data reduction in this paper:

Light Minimum at $JD_{\odot} = 2439995.4413 + 0^{\rm d}52067688 \cdot E$.

A period twice that adopted can be ruled out if one considers the double-wave variation of the Si II and He I lines. The amplitude for the secondary minimum is clearly smaller than for the primary minimum (Peterson, op. cit. and Khoklova, op. cit.).

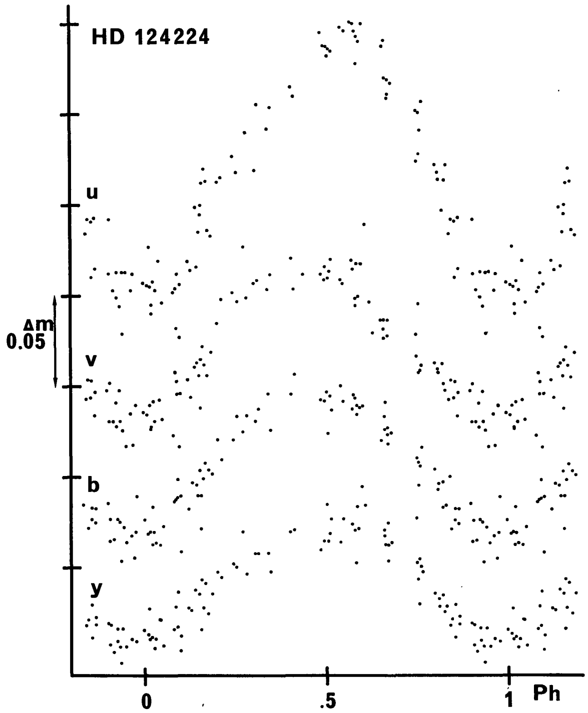


Fig. 1. Light curves of HD 124224 in the Strömgren system

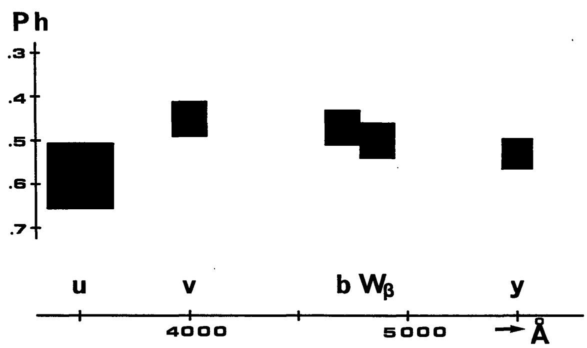


Fig. 2. The wavelength dependence of the phase of light maximum. The square size is proportional to the light amplitude

## Strömgren Photometry

Observations of HD 124224 were carried out in May 1974 at Cerro Tololo Interamerican Observatory by one

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Table 1

| Phase | $y$ | N$\beta$ | W$\beta$ | $\beta$ | $b$ | $v$ | $u$ | |
|---|---|---|---|---|---|---|---|---|
| 0.00 | .000 | .000 | .000 | 2.770 | .000 | .000 | .000 | Pole I |
| 0.25 | −.040 | −.046 | −.055 | 2.768 | −.055 | −.062 | −.070 | Equator |
| 0.50 | −.070 | −.097 | −.085 | 2.750 | −.080 | −.084 | −.142 | Pole II |
| 0.75 | −.040 | −.062 | −.045 | 2.750 | −.042 | −.038 | −.090 | Equator |
| 1.00 | .000 | .000 | .000 | 2.770 | .000 | .000 | .000 | Pole I |
| $\lambda$ (Å) | 5500 | 4860 | 4860 | | 4700 | 4100 | 3500 | |
| Phase of Maximum | .53 | .56 | .50 | .14 | .47 | .45 | .58 | |
| $\Delta m$ (max.) | .070 | .100 | .085 | .032 | .083 | .084 | .153 | |

N$\beta$...narrow-band H$\beta$ filter. – W$\beta$...wide-band H$\beta$ filter.

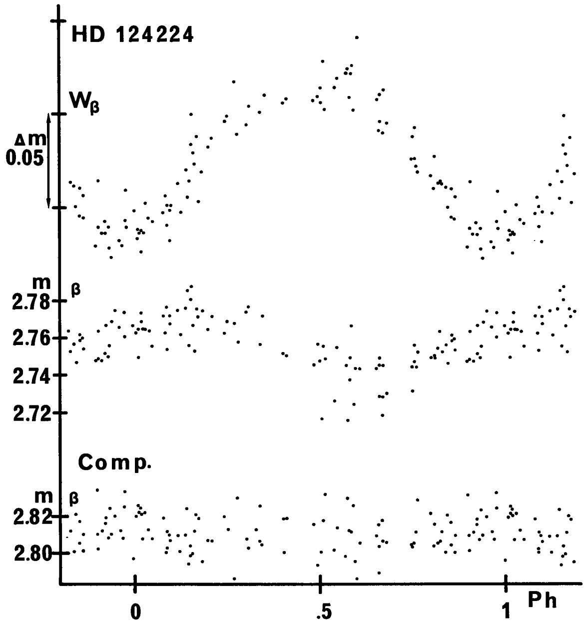


Fig. 3. H$\beta$-photometry. W$\beta$...wide band H$\beta$-filter

of us (W.W.) in Chile. In four of 16 nights, scans with the Harvard Spectrum Scanner were obtained with a 20 Å resolution and with equidistant wavelength steps of 20 Å. On the other 12 nights HD 124224 was observed in *uvby* and $\beta$ with a 16″ telescope. A mean extinction coefficient was derived from a mean of 9 observations of Strömgren standard stars per night.

HD 121607 ($V=5^{m}90$, A 3, HR 5244) was chosen as a comparison star. This object has been checked for light variations earlier by Blanco *et al.* (1971) and was found to be constant. Data reductions were done at the Vienna University Observatory, using special interactive reduction routines on a PDP-12-based computer system. The recent observations are plotted in a phase diagram as magnitude differences relative to the comparison star in Fig. 1.

Amplitude as well as phase of maximum are clearly a function of wavelength (filter). This is shown in more detail in Fig. 2, where the square sizes are proportional to the light amplitude. Table 1 gives a summary for the observations.

The $\beta$-index (Fig. 3) varies nearly in antiphase with the other colors and with a small amplitude of approximately $0^{m}02$. This is in agreement to Deutsch's (1952) statement that Balmer lines are constant to within his photographic accuracy. The mean $\beta$-index of $2^{m}760$ for this Ap-star is not in good agreement (Golay, 1974) with the H$\gamma$ line width, reported by Deutsch (op. cit.) as 12 Å. The H$\beta$ equivalent width should be about 9 Å according to several recent calibrations. Although the scatter in the $\beta$-index observations is considerable, we believe the periodic variation is real within our accuracy of $\pm 0^{m}003$. One will find from Fig. 3 that the $\beta$-maximum follows Pole I and $\beta$-minimum Pole II. The designation Pole I and II is an arbitrary one, since it will not be possible in the near future to measure the magnetic field with classical methods due to rotationally broadened lines. J. Hardorp (1975) brought our attention to Landstreet's measurements of the magnetic field with the photoelectric Balmer-line wing Zeeman method. The measurements do not show a significant change of the magnetic field, however, there are only few measurements available at present. More material has to be obtained for a final discussion and with a better distribution over a period. Landstreet's (1975) measurements are:

| JD 2440000+ | $H_{eff}$ (Gauss) | Phase |
|---|---|---|
| 0767.70 | 360 ± 310 | .18 |
| 1761.03 | 680 ± 1000 | .95 |
| 1809.72 | 1260 ± 700 | .46 |
| 1810.74 | 400 ± 700 | .42 |

Another instructive way to look at the photometric data is to plot magnitude differences relative to Pole I as a function of light phase and wavelength. The asymmetry of the light curves from Fig. 1 finds a counterpart in Fig. 4 for phase 0.25 and 0.75.

Line blocking as measured by the Strömgren index $m_1$ seems to be variable with an amplitude of $\pm 0.014$ mag. A study of a phase correlation between $m_1$, $b-y$ and DEP for approximatelly 100 Ap stars was performed by H. M. Maitzen (1976) and will be published soon. He

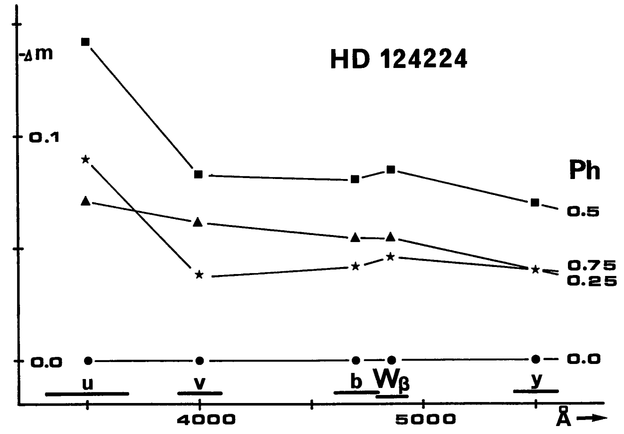

Fig. 4. Color changes of HD 124224 at different phases

found a mean $b-y=-0\overset{\mathrm{m}}{.}067\pm0\overset{\mathrm{m}}{.}003$, $m_1=0\overset{\mathrm{m}}{.}140\pm0\overset{\mathrm{m}}{.}014$ and DEP$=0\overset{\mathrm{m}}{.}020\pm0\overset{\mathrm{m}}{.}009$.

These values are in good agreement with those published by Cameron (1966): $u-b=-0\overset{\mathrm{m}}{.}700$, $b-y=-0\overset{\mathrm{m}}{.}059$, $m_1=0\overset{\mathrm{m}}{.}138$, $c_1=0\overset{\mathrm{m}}{.}564$ and $\beta=2\overset{\mathrm{m}}{.}774$. HD 124224 is the star H 3379 in the catalogue of Hauck and Lindemann (1973) where one finds for $v=5\overset{\mathrm{m}}{.}000$, $b-y=-0\overset{\mathrm{m}}{.}055$, $m_1=0\overset{\mathrm{m}}{.}135$, $c_1=0\overset{\mathrm{m}}{.}586$ and $\beta=2\overset{\mathrm{m}}{.}767$. In Table 1, the magnitudes N$\beta$ and W$\beta$ are listed individually since maxima occured at different phases. The magnitudes are differences from the comparison star and thus represent independant light curves.

## Short Time Fluctuations

During the best photometric night, from May 26 to 27, we looked for short time fluctuations in H$\beta$ and indeed found some indications of flares. The standard deviation for the $\beta$-index measurements of HD 124224 could be found to $\pm0\overset{\mathrm{m}}{.}008$, which is four times the standard deviation for the measurements of the comparison star (Fig. 5). Coincidently, these data were obtained while looking nearly at Pole II (phase 0.57 to 0.70). It would be very interesting to look at other phases for this effect. The standard deviation for the Ap-star and the comparison for the $m_1$-index observations are similar ($\pm0\overset{\mathrm{m}}{.}007$).

A simple explanation for this phenomenon could be flares in Hydrogen, that primarily affect the Balmer lines and hence the H$\beta$-narrow filter observations. This mechanism could be in agreement with observations published by Polosukhina (1974), who has found variable emission features on the wings of H$\alpha$ and H$\beta$ lines in spectra of the Ap-star HD 215441.

## Spectrum Scan Observations

A more detailed picture of the spectrum variations of this star at 20 Å resolution is shown by 8 spectrum scans at different phases in two channels with the Harvard Scanner. Two spectrum scans, obtained at phase 0.01 (channel 1) and phase 0.02 (channel 2), were taken as references for the other scans at phase 0.48, 0.51 and 0.64 (channel 1) and 0.49, 0.52 and 0.65 (channel 2). In the plot of the residual magnitudes (Fig. 6), all Hydrogen lines are clearly evident.

## Conclusion

The oblique rotator seems to be an appropriate model for this star. Considering the asymmetric light curves, one is tempted to assume a decentered dipole, which is

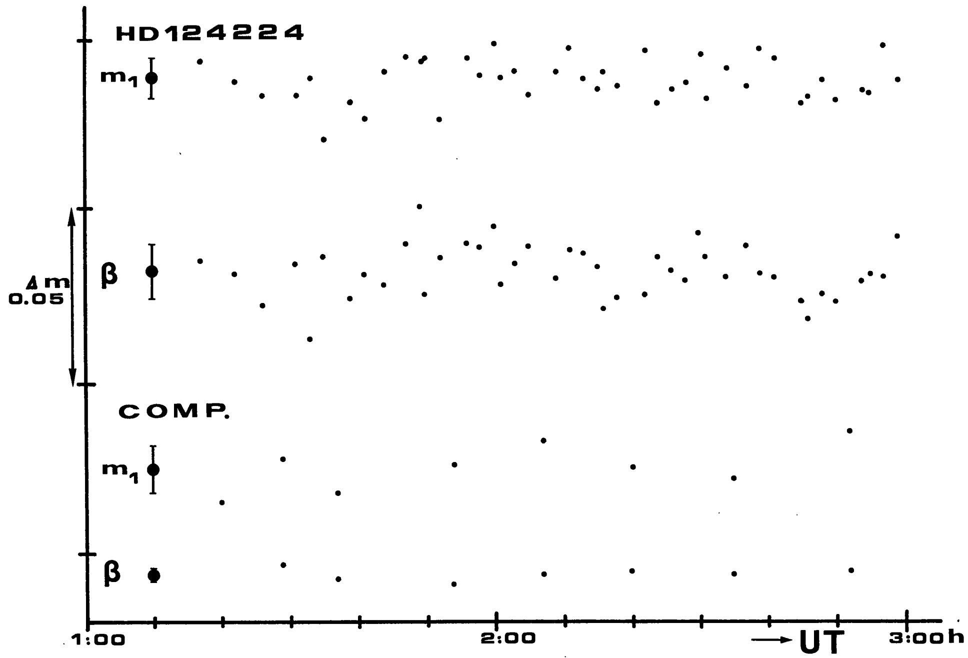

Fig. 5. Observations with high time resolution of $\beta$-index and $m_1$-index

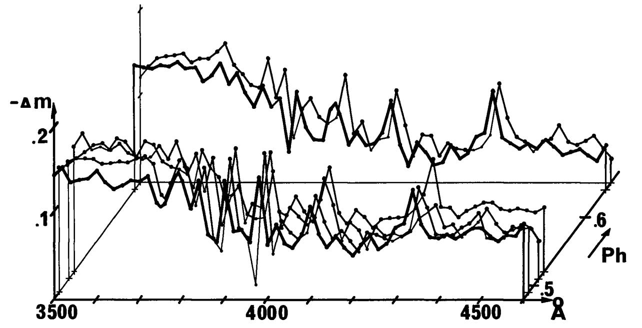


Fig. 6. Spectrum scans differenced ($\Delta m$) with respect to scans at phase 0.0

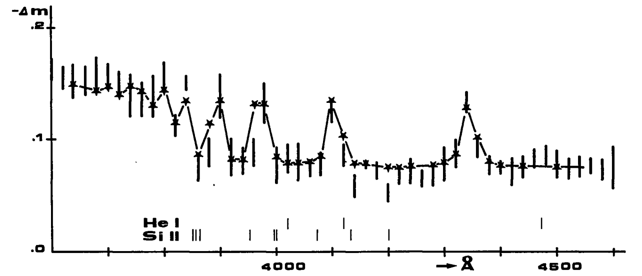


Fig. 7. Comparison between the computed model atmosphere for phase 0.5 differenced with respect to phase 0.0 (asterisk) and the observations (bars). The bars indicate the magnitude range for 6 spectrum scans at phase 0.48, 0.49, 0.51, 0.52, 0.64 and 0.65 also differenced to scans at phase 0.01 and 0.02. Wavelengths for some Si II and He I lines are also indicated, mainly those investigated by Khoklova (1970)

not surprising since this star rotates very fast. Following the van-Allen belt model for magnetic stars published by K. Rakosch *et al.* (1974), we tried to find two sets of effective temperatures and effective gravities for Pole I and II which reproduce the wavelength-dependence of light-curve amplitudes.

As has been demonstrated by Rakosch *et al.*, it is possible to explain the variation of visible light-curve amplitudes with wavelength in the case of $\alpha^2 CVn$ by assuming different $T_{\rm eff}$ and $\log g_{\rm eff}$ at the magnetic poles and the magnetic equator. Recently, I. Kopylov *et al.* (1975) verified the predicted range of temperature and gravity changes in $\alpha^2$CVn by observation.

To compute the best $T_{\rm eff}$ and $\log g_{\rm eff}$ values we used the simple Balmer-line blanketed model atmosphere published by Mihalas (1966). A linear extrapolation was necessary for $\Theta$-values less than 0.40. The computations proved to be quite sensitive to $\Delta\Theta$ and $\Delta \log g$ between Pole I and Pole II. Therefore the van-Allen belt model computations can only be taken as a first-order attempt to find a model for HD 124224.

The fit was assumed to be optimal, when the *uvby* amplitudes and the observed spectrum scan amplitudes from 3500 Å to 4600 Å could be reproduced within a $0\overset{\rm m}{.}01$ limit. We adopted this rather high limit because of the very simple model atmosphere used. Forcing a better agreement between observation and computation would imply an unreal accuracy in the model. The fit to $0\overset{\rm m}{.}01$ mag. could be achieved in all colors, except in $v$. However, a discrepancy of $0\overset{\rm m}{.}02$ is not too serious, if one considers the peculiarities in the stellar atmosphere—for example the strong Si lines—which the Mihalas-model does not take into account (Fig. 7). The following values were finally adopted for phase 0.0 and 0.5:

| | $\Theta_{\rm eff}$ | $\log g_{\rm eff}$ |
|---|---|---|
| Pole I | 0.375 | 3.60 |
| Pole II | 0.360 | 3.45 |

The resulting light amplitudes are:

| | $u$ | $v$ | $b$ | $y$ |
|---|---|---|---|---|
| computed | 0.146 | 0.106 | 0.074 | 0.071 |
| observed | 0.142 | 0.084 | 0.080 | 0.070 |

Following a calibration for Pop. I B-type stars by D. Philip and B. Newell (1975, p. 164) the effective temperature can be computed from the equation:

$$\Theta_{\rm eff} = 0.202\,[u-b] + 0.196$$

for the interval $0\overset{\rm m}{.}44 \leqq [u-b] \leqq 1\overset{\rm m}{.}10$.

This formula gives $\Delta\Theta_{\rm eff} = 0.010$ using the measurements quoted in Table 1 and the relation (Philips and Newell, 1975, p. 162):

$$[u-b] = (u-b) - 1.61 \cdot (b-y)$$

This is in good agreement with $\Delta\Theta_{\rm eff} = 0.015$, found by model computations in this paper and by spectroscopic studies (Khoklova, op. cit.). This effective temperature change of 600 K is close to the mean reported by Peterson (op. cit.), who used the relation $\Theta = (B-V) + 0.50$ and found $\Delta T_{\rm eff} = 300$ K, but found that $\Delta T_{\rm eff} = 500$ K from H$\gamma$ line profile changes.

Our mean effective temperature (13700 K) is higher than the value reported by Peterson and Khoklova, but close to the temperature adopted by C. Megessier (1971). She gives the value $\Theta_{\rm eff} = 0.37$.

Our mean $\log g_{\rm eff}$ values also agree with Peterson's, who found a mean $\log g = 3.5$. Megessier adopts the same value. We would like to note that it was impossible to find a set of two $\Theta_{\rm eff}$ values for computing the observed light variations, without assuming a variable effective gravity. In our case, a lower effective temperature corresponds to a lower effective gravity. This is in agreement with the investigations published by Kopylov (op. cit.).

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*Note added in proof:* J. Landstreet reports a new magnetic field measurement in $H_2$ (private communication) for JD 2442593.67: $H_{\rm eff} = 400 \pm 270$ gauss.

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