

ON THE LONG-TERM VARIABILITY OF THE K2e STAR HD 224085

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ABSTRACT

HD 224085 is a late-type, emission-line star with light variations that have been interpreted as due to starspots. We have studied the long-term variability of this object using the Harvard archival plate collection. In contrast with previously studied BY Draconis variables, HD 224085 was essentially constant in mean light for ~ 40 years before beginning to exhibit changes ≥ 0.3 mag, both in the short-period variability and in mean light. The data suggest that stars with spots may pass through long periods of relative inactivity.

Subject headings: stars: binaries — stars: emission-line — stars: individual — stars: late-type

I. INTRODUCTION

Observations of the single-lined spectroscopic binary HD 224085 (K2e) revealed light variations up to 0.3 mag with a period near 6^d.75 (Chugainov 1976; Ruciński 1977). This variability has been attributed to the presence of starspots rotationally modulating the observed flux (Chugainov 1976), as is apparently the case for two classes of late-type emission-line stars, the dwarf BY Draconis variables (Chugainov 1966; Krzeminski 1969; Bopp and Evans 1973; Torres and Ferraz Mello 1973), and the giant RS Canum Venaticorum stars (Eaton and Hall 1979). However, HD 224085 is unusual in two respects. It is not clear whether it should be classified as a BY Draconis variable or an RS Canum Venaticorum system; and the presence of the Li I $\lambda 6707$ line (Ruciński 1977) suggests that this star is extremely young.

The modern photoelectric observations indicate that both the amplitude of spot variation and the mean light level of the star are not constant. In an earlier paper (Phillips and Hartmann 1978) we explored the long-term variability of four BY Draconis variables by using the Harvard archival plate collection. That study found a slow variability of 0.3–0.4 mag in two of the stars, with time scales of decades. In this paper we use the same techniques to study the long-term behavior of HD 224085. The results are qualitatively different, with important implications for understanding the mechanism producing the light variations.

II. DATA REDUCTION

Plates reduced for HD 224085 covering the period 1900–1951 were selected from the AC, CA, and CY series of Harvard patrol plates (3.81 cm aperture, 10' mm⁻¹). For 1968–1977 the Damon patrol plates were used (4.06 cm aperture, 9'67 mm⁻¹). The image densities were measured with the Askania iris photometer; each star was measured twice and the densities were averaged. Ten stars were used to provide a magnitude sequence. For the faintest stars, photographic magnitudes were taken from the SAO catalog. It was

necessary to define photographic magnitudes for the three brightest stars by extrapolating the magnitude sequence. Average magnitudes for these stars were found from 12 plates chosen at random from the 168 plates measured. While errors from extrapolation could certainly be present, we argue later from the agreement of photographic measurements with simultaneous photoelectric data that the error involved in this extrapolation is no more than ~ 0.07 mag.

The photographic magnitudes were put on a B magnitude scale using a zero-point shift derived from Ruciński's (1977) comparison star BD +27°4648. Since Ruciński gives only V and $b - y$, we converted this color to $B - V$ by calibrating Olson's (1974) $b - y$ data with the $B - V$ s listed in the Blanco *et al.* (1968) catalog.

Figure 1 presents the yearly mean magnitudes $\bar{m}$, with the plotted variances $\sigma = [\sum (m_i - \bar{m})^2 / (N - 1)]^{1/2}$ for the N plates in each year. To these data we have added more recent photoelectric data from Eggen (1968), Argue (1966), Chugainov (1976), and Ruciński (1977). In all cases we have converted V magnitudes to B by assuming $B - V = 1.01$. This is justified on the basis of the small color variation seen by Ruciński (1977), the agreement of Eggen (1968) and Argue (1966) on $B - V$, and also from our $B - V$ versus $b - y$ calibration, which yields a mean $B - V = 1.01$ for Ruciński's data.

For the years in which photoelectric and photographic data are available, 1974 and 1976, the agreement justifies our magnitude sequence and zero-point correction. The mean photographic magnitudes are systematically ~ 0.06 mag fainter than the photoelectric data, a difference within expected errors.

III. DISCUSSION

From Figure 1 it appears that a qualitative change in the behavior of HD 224085 occurred around 1945. Prior to this time, the star appears to be roughly constant in photographic magnitude; afterward, fluctuations in mean light occur, and the standard

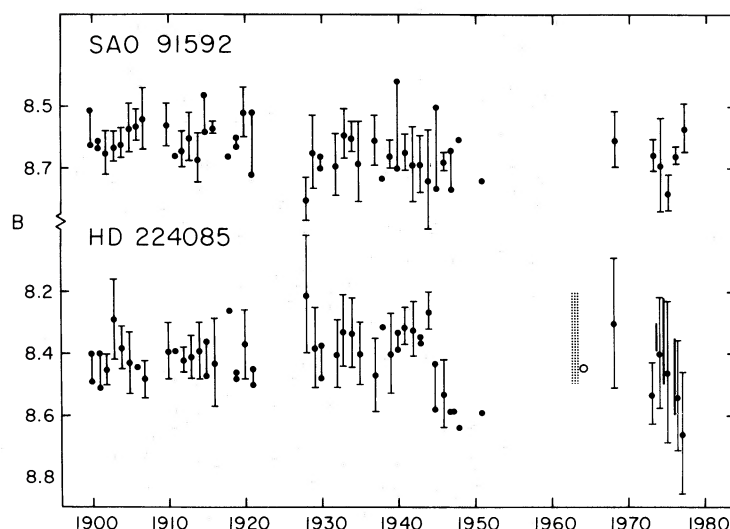


FIG. 1.—Yearly mean photographic magnitudes for the variable HD 224085, plotted with the comparison star SAO 91592. The error bars are the standard deviation of a single plate from the yearly mean. The average number of plates per year is ~ 4 . Single points and double, connected points represent years for which there are only one or two plates, respectively; for the latter, no means or variances were calculated. Included for years after 1962 are photoelectric B magnitudes, from the following sources: *dotted box*, data from Eggen (1968); *open circle*, data from Argue (1966); *straight lines*, data for 1974 from Chugainov (1976), and data for 1976 from Ruciński (1977). The height of the symbols for the photoelectric data indicates the range of the $6^{\text{d}}75$ variation. The box indicates uncertainty in the exact dates of Eggen's (1968) observations.

deviations grow larger. In the following subsections we make these statements more precise.

a) Analysis of Yearly Mean Light

In the interval 1900–1940 there is no obvious change in mean light other than the brightening in 1928. While this change may be real, the magnitude of the comparison star is also discrepant. Therefore the data for 1928 must be accorded low weight.

Around 1945 the variable star exhibits markedly different behavior from the comparison star. This change is significant despite the fact that there are fewer plates for the years 1945–1951 than the average of four plates per year for the rest of the observations. If we group the eight plates for this period together, they define a decline of nearly 0.25 mag, while the comparison star remains nearly constant. Therefore a real change in mean light appears to have occurred at this point.

The data from 1968 on show the average magnitude of HD 224085 varied by ≥ 0.35 mag, nearly twice the range of the comparison star. In addition, we have photoelectric data for 1974 and 1976; these data have essentially no error compared with the photographic results, and have been plotted in Figure 1 with bars indicating the range of the $6^{\text{d}}75$ amplitude. The average photographic and photoelectric data for these years agree to about 0.07 mag, increasing our confidence in the photographic results. Most important, the photoelectric results also show the same decline ~ 0.14 mag in mean light that can be seen in the photographic data for these years.

To investigate this variability more fully, we have computed deviations δ_i of the yearly mean magnitude

$\bar{m}_i$, from an 11-point running mean centered at year i . For convenience of analysis we have divided the data into groups defined by the gaps in the plate material, running from 1900 to 1921, 1929 to 1951, and 1968 to 1977. At each endpoint year, five data points were reflected to compute the running mean. We have dropped the data for 1928 and the single data point for 1918 as being of low weight.

The results of this calculation show that the comparison star δ 's are nearly all contained in an error envelope of $\pm e$, where $e = 0.07$ mag. The δ_i for HD 224085 show three big spikes: one $\sim 3e$ centered at 1943, one with a total range of $5e$ in the period 1968–1977, and a smaller spike $\sim 2e$ in 1903. For the other years, the error envelope of the variable star is essentially identical to the envelope of the comparison star δ 's. Therefore we conclude that, apart from a brightening of marginal significance in 1903, the yearly mean light of HD 224085 remained constant in the interval 1900–1940; afterward, light variations on the order of 0.3 mag appeared.

The determination of changes in mean light over time scales of decades is complicated by the presence of gaps in the data. From the behavior of the comparison star in Figure 1 it can be seen that systematic drifts of up to 0.10 mag may occur, a figure comparable to the results found in a previous study of BY Draconis variables (Phillips and Hartmann 1978). We conclude that HD 224085 has been constant in light to within ~ 0.10 mag in the interval 1900–1945.

The modern Damon plates (1968–1977) might be systematically different from the earlier plates because of differing emulsions; however, from the behavior of the comparison star we are able to rule out changes greater than 0.10 mag. The average number of plates

per year is the same for the period after 1967 as before, so that we may treat the data as a homogeneous set. This is also suggested by the fact that the range of yearly mean magnitudes for 1968–1977 is essentially the same as the range for 1940–1951.

Comparing the roughly constant behavior from 1900 to 1940 with the most recent data, it is clear that the constant light level is well above minimum light (~ 0.2 mag). If we identify the data for 1941–1944 and 1968 as representing maximum light, it appears that the constant light level is approximately 0.1 mag fainter than maximum; however, given the presence of drifts of this size in the comparison star, the result is uncertain.

Clearly, changes in light during those years for which there is no plate material cannot be ruled out, nor can the possibility of mean light changes $\lesssim 0.10$ mag during the interval 1900–1940 be excluded. Despite these qualifications, it is clear that HD 224085 was relatively constant during this period when compared with either of the previously studied variables BY Draconis or CC Eridani (Phillips and Hartmann 1978), which would show variability ~ 0.3 mag in a similar 40 year span. Only after 1940 does the behavior of HD 224085 resemble that of the other BY Draconis stars.

b) Short-Period Variability

In general there is not enough plate material to find light curves for the 6475 variation. However, such variability should show up in a statistical sense by increasing the calculated standard deviations.

For the period 1900–1945 the average standard deviation for HD 224085 is 0.09 mag, while that for the comparison star is 0.08 mag. In contrast, the average deviation for the variable during the period 1968–1977 is 0.18 mag, while the comparison star remains at 0.09 mag. The deviation for the variable star is consistent with errors of 0.09 mag convolved with a real sinusoidal variation of semiamplitude ~ 0.15 mag, which is consistent with the variation observed by Chugainov (1976) and Ruciński (1977). (Note that the amplitude for the spring of 1974 may be a lower limit to the true amplitude, as the observations do not appear to cover phases near maximum light.) This result strongly suggests that the short-period amplitude was small during the interval 1900–1940, for we would otherwise expect to see a similar difference in the standard deviations of the variable and the comparison star.

To summarize, prior to about 1940 the mean light level of HD 224085 was constant to within ~ 0.10 mag, and the standard deviations of the yearly means of the variable were the same size as those of the comparison star, suggesting that no large 6475 amplitude was present. This does not rule out short-period or mean light variability completely. But it is considerably different from the behavior of previously studied “spot” stars which have light curves extending over a long time interval (Phillips and Hartmann 1978). After 1940, activity increased, measured in two ways: the mean light level varied by ~ 0.35 mag, nearly

twice the change in the presumably constant comparison star; and the standard deviations of the variable were twice as large as expected, which we interpret as the result of the 6475 light variation.

c) Implications for the Mechanism of Variability

The data presented here suggest that stars exhibiting BY Draconis-type light variations may pass through periods of relative inactivity, as measured by the small size of short-period amplitudes and the absence of large changes in the mean light level. This behavior is in accordance with the suggestion of Bopp and Espenak (1977) that all dKe and dMe stars are BY Draconis variables, but pass through quiescent phases so that only a fraction of the stars vary at a given epoch. Further monitoring of dMe stars not known to be BY Draconis variables is encouraged.

On the Sun, active regions are correlated with spots. If the spots invoked on the BY Draconis variables to explain the changes in light are analogous to sunspots, changes in the chromospheric emission lines should be related to the light variability. If spectra taken of HD 224085 before 1940 exist, it would be possible to see if the emission lines were weaker than at present, as expected from the solar analogy. Such observations, if available, would encourage parallels between solar and stellar activity.

Phillips and Hartmann (1978) suggested that spot cycles analogous to the solar cycle might show up in the light variations of BY Draconis stars. There are no obvious periodicities in the observations of HD 224085, particularly on the ~ 10 year periods or time scales found by Wilson (1976) in the calcium emission of some G and K dwarfs. Further study should be undertaken to determine whether HD 224085 is truly representative of the BY Draconis variables, or is better associated with the RS Canum Venaticorum variables (Ruciński 1977).

Finally, these observations have implications for the exact nature of spots. Vogt (1975) first attempted to account for the changes in the mean light level of BY Draconis in terms of a spot model. This point was subsequently expanded by Oskanyan *et al.* (1977), who found that spots could be either bright or dark, partially depending upon the choice of “immaculate” magnitude, i.e., the brightness of the star when no spots are present. If we identify the period 1900–1940 as a quiescent phase of the star, then the immaculate magnitude would be close to maximum light, possibly ~ 0.1 mag below maximum. Oskanyan *et al.* (1977) similarly suggested an immaculate magnitude approximately 0.1 mag below maximum for BY Draconis, implying the existence of bright spots. The presence of 0.10 mag drifts in our data prevents us from saying anything certain on this point. However, the quiescent light is clearly above minimum light, suggesting that on the spot model, dark spots must be favored.

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