Pub. Astron. Soc. Pacific, Volume 85, December 1973

# THE NATURE OF THE LIGHT VARIATIONS OF HD 188041

TERRY J. JONES AND SIDNEY C. WOLFF
Institute for Astronomy, University of Hawaii

*Received 28 August 1973*

Four-color (*uvby*) observations of the peculiar A star HD 188041 have been obtained at the Mauna Kea Observatory. A combination of flux redistribution from the ultraviolet and local line-blocking effects can explain the light variations of this star. It is suggested that new spectrum variables with compositions similar to that of HD 188041 can be discovered by *uvby* photometry.

*Key words:* peculiar A star — photometric variability — line blocking

## I. Introduction

Many Ap stars are both spectrum and light variables, and Peterson (1970) and Wolff and Wolff (1971) have suggested that spectrum and photometric variability may be causally related, since variations in line and continuous opacity in the region below λ3000 will produce changes in the observed flux longward of λ3000. In the rare-earth spectrum variables, *V* light maximum usually coincides with rare earth maximum, as would be expected if variable line-blocking due to ultra-violet rare-earth lines is the dominant cause of the *V* light variations. In many stars, however, the *v* (λ4100) light curve shows a minimum at the phase of rare-earth maximum. It has been proposed (Wolff and Wolff 1971) that the minimum in *v* may be the result of local line-blocking effects, since the strongest line absorption in the visible spectrum occurs in the region included in the *v* passband (Wolff 1967). In the present paper photometric and line-blocking measurements of HD 188041 (HR 7575), an Ap star which exhibits a deep minimum in *v* at rare-earth maximum, are used to test this hypothesis.

## II. Observations

The observations were made with a 61-cm Boller and Chivens telescope at the Mauna Kea Observatory. The equipment and techniques of observation are described elsewhere (Wolff and Morrison 1973). The results of *uvby* photometry of HD 188041 over a period of 2-½ years are listed in Table I and plotted in Figure 1 according to a 224.5-day period derived from the star's magnetic field variations (Wolff 1969*b*). As magnetic field measurements are available as far back as 1947 (Babcock 1954), this period represents the most accurate available. The phases, which have been calculated from the elements

$$\mathrm{JD}_{\odot}\ (\text{magnetic minimum}) = 2432323 + 224.5E,$$

are given in the second column of Table I. Magnetic maximum occurs at phase 0.55. Rare-earth maximum occurs between phases 0.45 and 0.50 (Babcock 1954), which is slightly ahead of magnetic maximum. The lines of the Fe-peak elements vary in phase with the rare earths but with smaller amplitude (Wolff 1969*a*).

The *V* curve, which was derived by transforming *y* to *V* (Crawford and Barnes 1970), varies in phase with the rare earths with maximum light at about phase 0.48. The *b* curve is relatively flat with a suggestion of some variation similar to the *V* curve. The *v* curve, however, shows a sharp minimum at the phase of maximum line strength, and the question is whether the variation in *v* can be accounted for by changes in the strengths of the lines in the wavelength region included in the *v* filter.

Line blocking in the visible spectrum was measured on direct intensity microphotometer tracings of spectrograms obtained at phases 0.54 and 0.83. The spectrograms traced were

TABLE I

PHOTOELECTRIC OBSERVATIONS

| JD⊙ 2440000+ | Phase | V | $b-y$ | $m_1$ | $c_1$ |
|---|---|---|---|---|---|
| 0754.95 | 0.55 | +5.631 | +0ᵐ056 | +0ᵐ378 | +0ᵐ666 |
| 0758.98 | 0.58 | +5.637 | +0.048 | +0.379 | +0.679 |
| 0761.96 | 0.59 | +5.632 | +0.058 | +0.359 | +0.695 |
| 0762.95 | 0.60 | +5.640 | +0.047 | +0.372 | +0.696 |
| 0782.94 | 0.68 | +5.643 | +0.043 | +0.340 | +0.754 |
| 0783.89 | 0.69 | +5.645 | +0.044 | +0.340 | +0.753 |
| 0787.88 | 0.71 | +5.642 | +0.049 | +0.331 | +0.757 |
| 0789.90 | 0.72 | +5.645 | +0.044 | +0.336 | +0.763 |
| 0804.88 | 0.78 | +5.644 | +0.049 | +0.316 | +0.790 |
| 0805.87 | 0.79 | +5.644 | +0.045 | +0.320 | +0.786 |
| 0828.80 | 0.89 | +5.647 | +0.042 | +0.320 | +0.793 |
| 0831.81 | 0.90 | +5.645 | +0.046 | +0.312 | +0.801 |
| 0847.78 | 0.97 | +5.638 | +0.049 | +0.306 | +0.809 |
| 0853.76 | 0.00 | +5.645 | +0.043 | +0.316 | +0.797 |
| 1169.89 | 0.41 | +5.628 | +0.058 | +0.391 | +0.642 |
| 1170.87 | 0.41 | +5.628 | +0.058 | +0.394 | +0.635 |
| 1184.90 | 0.47 | +5.626 | +0.060 | +0.395 | +0.626 |
| 1185.91 | 0.48 | +5.634 | +0.058 | +0.397 | +0.632 |
| 1204.82 | 0.56 | +5.628 | +0.059 | +0.365 | +0.682 |
| 1210.86 | 0.60 | +5.637 | +0.052 | +0.367 | +0.695 |
| 1233.75 | 0.69 | +5.634 | +0.052 | +0.329 | +0.769 |
| 1234.75 | 0.70 | +5.637 | +0.045 | +0.340 | +0.750 |
| 1243.74 | 0.74 | +5.637 | +0.050 | +0.327 | +0.767 |
| 1245.73 | 0.75 | +5.643 | +0.049 | +0.319 | +0.778 |
| 1526.97 | 0.00 | +5.642 | +0.047 | +0.316 | +0.792 |
| 1529.90 | 0.01 | +5.640 | +0.046 | +0.319 | +0.796 |
| 1562.86 | 0.16 | +5.637 | +0.042 | +0.337 | +0.763 |
| 1590.78 | 0.28 | +5.629 | +0.056 | +0.366 | +0.693 |
| 1592.78 | 0.29 | +5.630 | +0.055 | +0.367 | +0.691 |
| 1612.74 | 0.38 | +5.630 | +0ᵐ057 | +0ᵐ390 | +0ᵐ642 |

obtained by George Preston with the coudé spectrograph of the 305-cm telescope at Lick Observatory and have an original dispersion of 2 Å mm$^{-1}$. For the spectrum within both the $b$ and $y$ filters the ratio of the area contained within the lines to the total area included under the continuum was measured with a planimeter. These ratios were used to calculate the correction in magnitude to the observed colors for line-blocking following the procedure outlined by Wildey et al. (1962). Unblanketed fluxes were obtained from Mihalas' model atmospheres for A-type stars (Mihalas 1966) using $\theta = 0.55$ (Wolff 1967) and assuming $\log g = 4$.

The results of these measurements are given in Table II. The values for $b$ and $v$ are those actually observed for the star at those phases. The quantities $\Delta v$ and $\Delta b$ are the calculated corrections to the observed colors for line-blocking.

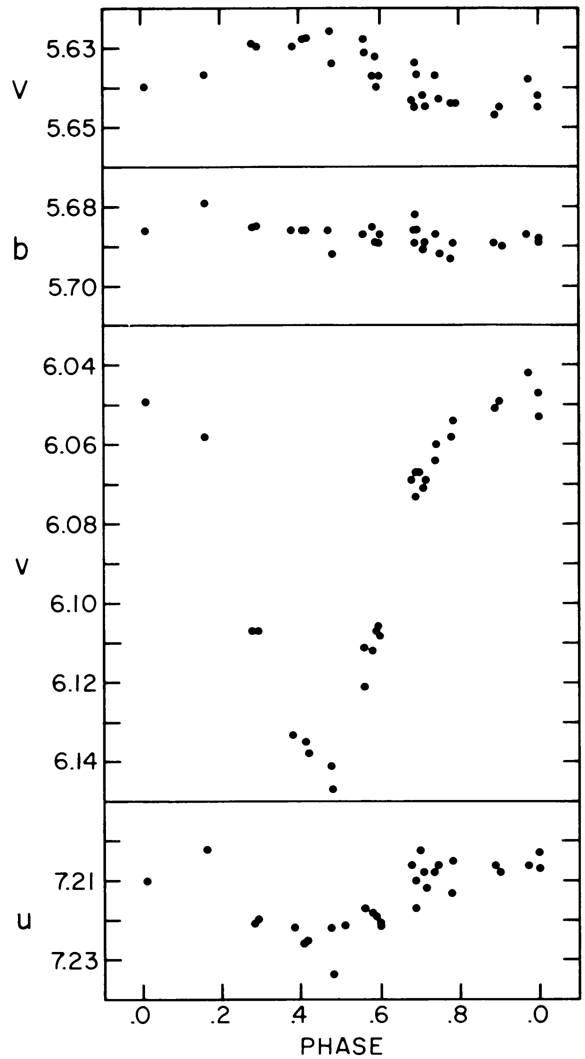


FIG. 1 — The light variations of HD 188041 plotted according to the ephemeris JD$_\odot$ (magnetic minimum) = 2432323 + 224.5E.

### III. Discussion

As the line-blocking measurements show, the strengths of the lines in HD 188041 decrease between phases 0.54 and 0.83, and this decrease will affect the *b* and *v* magnitudes in two ways. First, the weakening of lines in the *v* and *b* filter passbands will cause the emergent flux in these bands to increase. At the same time, the line opacity produced by rare-earth and Fe-peak elements in the ultraviolet also decreases, and the amount of flux redistributed from the ultraviolet into the visible is reduced. A detailed model-atmosphere analysis would be required in order to estimate directly the quantitative effects in the visible of changes in the line opacity in the ultraviolet. However, calculations by Peterson (1970) of changes in the emergent flux in the visible due to variations in the ultraviolet opacity of Si show that these changes are nearly independent of wavelength in the region λ4000 to λ6000. Since the effect of any increase in ultraviolet opacity is to redistribute flux into the visible regions of the spectrum and increase the gas temperature for a given effective temperature and since the slope of the Paschen continuum in this temperature range varies only slightly for small changes in temperature, Peterson's result should apply at least approximately regardless of the precise nature of the source of the variable ultraviolet opacity. We would expect, therefore, that the variations in *v* and *b* due to changes in the amount of redistributed ultraviolet flux would be nearly equal.

The measurements of line blocking indicate that, due to the decrease in the strength of the lines included in the *b* filter passband, the *b* magnitude should brighten by about $0^m.03$ between phases 0.54 and 0.83. In fact, the photometric observations show that *b* is essentially constant during this interval. If the light variation is to be entirely accounted for in terms of variations in line strength, then we must assume that, due to the decrease in line opacity in the ultraviolet, the redistributed flux at λ4650 has decreased by about $0^m.03$. This decrease, then, counterbalances the expected brightening due to the change in local line blocking, and consequently no light variations are observed in the *b* filter passband. In the *v* passband, the decrease in line blocking should produce a brightening of about $0^m.10$. However, based on the results from the *b* filter, we would expect that because of the reduction in redistributed flux the observed variation would be less than this by about $0^m.03$. The observed change is $0^m.068$.

The *u* and *v* light curves can be accounted for qualitatively, at least, by the same mechanism. In the *u* passband the measured line-blocking coefficients are smaller than in *v* but larger than in *b* (Wolff 1967), and local variations in line strength would be expected to

TABLE II

LINE-BLOCKING MEASUREMENTS

| Phase | 0.54 | 0.83 |
|---|---|---|
| Plate | ECZ 4365 | ECZ 4562 |
| $v$(mag.) | +6.123 | +6.055 |
| $b$(mag.) | +5.688 | +5.690 |
| $\Delta v$(mag.) | −0.476 | −0.370 |
| $\Delta b$(mag.) | −0.279 | −0.248 |

dominate the light curve. In $y$, the blocking effects are smaller than in any of the other three filters and variations in the redistributed flux are apparently the most important factor in determining the magnitude at λ5450.

Several other Ap stars, including HD 71886 (Wolff and Wolff 1971) and 73 Draconis (Stepień 1967), have $v$ light curves that also show a pronounced minimum at the time of rare-earth and $V$-light maximum. All the stars with light curves of this kind are rich in rare earths, particularly Gd and Eu. The observations of HD 188041 show that, for this star, spectrum and photometric variability are causally related. We suggest that the same result applies to other stars with similar light curves and that it is therefore possible to identify new rare-earth spectrum variables with compositions similar to that of HD 188041 by photometric techniques.

We are indebted to George Preston for making available to us the microphotometer tracings of the spectrograms of HD 188041. We also wish to thank Nancy Morrison for her assisance with the photometry. This research was supported in part by a grant (GP-29741) from the National Science Foundation.

REFERENCES

Babcock, H. W. 1954, *Ap. J.* **154**, 66.
Crawford, D. L., and Barnes, J. V. 1970, *A.J.* **75**, 978.
Mihalas, D. 1966, *Ap. J. Suppl.* **13**, 1.
Peterson, Deane M. 1970, *Ap. J.* **161**, 685.
Stepień, Kazimierz 1967, *Ap. J.* **153**, 165.
Wildey, R. L., Burbidge, E. M., Sandage, A. R., and Burbidge, G. R. 1962, *Ap. J.* **135**, 94.
Wolff, S. C. 1967, *Ap. J. Suppl.* **15**, 21.
—— 1969*a*, *Ap. J.* **157**, 253.
—— 1969*b*, *ibid.* **158**, 1231.
Wolff, S. C., and Morrison, N. D. 1973, *Pub. A.S.P.* **85**, 141.
Wolff, S. C., and Wolff, R. J. 1971, *A.J.* **76**, 422.