Astron. Astrophys. 263, 161–164 (1992)

ASTRONOMY AND ASTROPHYSICS

The outstanding photometric variations of the Ap star HD 7676 = VV Scl

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Received May 13, accepted May 26, 1992

Abstract. Contrary to what was formerly believed, VV Scl is not an eclipsing star, but an α CVn type variable, the period of which is $P = 5\overset{d}{.}0976 \pm 0\overset{d}{.}0001$. The range of the luminosity variation is remarkably large for an Ap star, especially in B of Johnson's system, and in b and mostly in v of Strömgren's one. A secondary minimum appears near the maximum in B, b and v. The main minima are in phase in all colours.

Key words: photometry – stars: chemical peculiar – stars: variable – stars: individual: VV Scl

1. Introduction

The luminosity variations of HD 7676 ($V = 8.3$, spectral type: A5p SrCrEu) have been detected by Cousins and Stoy (1962). On the basis of their B measurements and other new ones, all in Johnson's system, Strohmeier (1965) claimed that it is an eclipsing variable of period $2\overset{d}{.}47962$ with a double-wave variation curve. But from the short range in V in regard to the B-range, and from the shape of the curve (probably not double-waved), Renson (1991) concluded that it is not an eclipsing variable. It was most probable that the variations were of the α CVn type, but with a range in B that is among the largest known for Ap stars.

Long-period aliases of the value originally deduced by Strohmeier were also possible. In order to get more precise light curves, and so to be able to decide on the true nature of the variation, we analyzed observations made at La Silla (ESO) in the frame of the Long-Term Photometry of Variables programme (LTPV; see Sterken 1983, 1986; also Manfroid et al. 1991).

2. Analysis of the results

The new measures have been made in the *uvby* system with the Danish 50 cm telescope. The reductions were made with the algorithm described by Manfroid (1985). After discarding a widely discordant observation obtained on a night of poor photometric quality, there remain 77 valid measurements, from July 30 to November 30, 1990, and from June 8 to October 1, 1991. The comparison star was HD 7259 = HR 358.

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The search of the period was carried out with Renson's algorithms (Renson 1978, 1980) for all the colours and colour-indices, and it very clearly led to the value $5\overset{d}{.}0980 \pm 0\overset{d}{.}0015$ for all of them.

Renson's θ_1 and θ_2 algorithms applied to the 17 B values deduced from the table published by Strohmeier (1965) also undoubtedly give $P = 5\overset{d}{.}098$ (note that for the numerous ESO measurements, applying the θ_1 method was quite sufficient.) This is also true for the 17 $B - V$ values. In fact, the period proposed by Strohmeier – who considered the variation to be double waved – is the double of $1\overset{d}{.}24$, itself an alias of the correct $5\overset{d}{.}1$ period. Though the Cape Observatory measurements are much less numerous and the observational error larger, the precision they yield for the period is about the same because the time basis is larger, 688 d between the first epoch and the last one (as compared to 428 d for the ESO measures).

In order to get a more precise value of P, it is useful to compare both sets of measurements. Since the four *uvby* colours vary in phase – though with different amplitudes and different shapes of the curves– we deduce that B also vary in phase, particularly with b and v. The comparison gives the final value

$$P = 5\overset{d}{.}0976 \pm 0\overset{d}{.}0001.$$

The next probable value, $5\overset{d}{.}0998$, lies somewhat outside the error interval obtained in the preceeding step. Moreover, it can be excluded by using the epochs quoted on the last page of Strohmeier's paper, in which the star was found to be fainter than mag. 8.7. With $P = 5\overset{d}{.}0976$ the phases of those epochs are close to the phase of minimum light as expected (see points with arrows on Fig. 1a), while with $5\overset{d}{.}0998$ they stray from the minimum, the first ones being even at the maximum light. Thus the precise value for the period is unambiguously settled, in spite of the more than thirty years between the two sets of measurements.

3. Discussion

Once again it appears that a wrong period had been adopted because a reliable method of period determination was lacking. A wrong period – often an alias of the correct one – can yield a good representation of the variation, such as in the figure of Strohmeier's paper.

Figure 1 displays the light variations of VV Scl as a function of the phase computed with $P = 5\overset{d}{.}0976$, respectively for B, y, b, v, u, $B - V$, $b - y$, m_1, c_1. The chosen origin is J.D. 2 448 381.0,

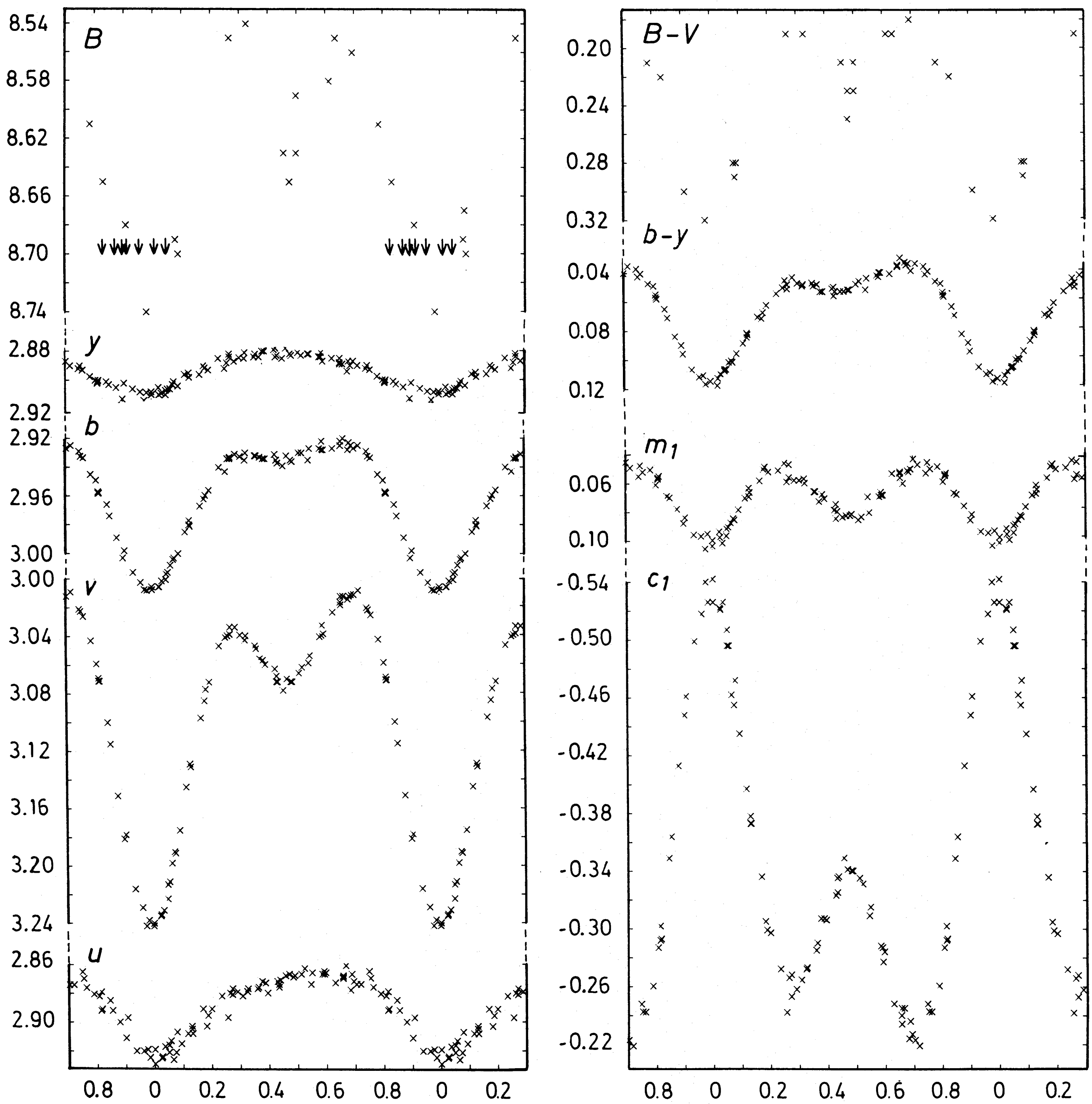

Fig. 1. Light variations of VV Scl as a function of the phase computed with $P = 5^{\mathrm{d}}.0976$, respectively for B, y, b, v, u, $B-V$, $b-y$, m_1, c_1. The chosen origin is J.D. 2 448 381.0. Arrowed dots represent the B observations listed in the last table of Strohmeier's paper ($B \geq 8.7$)

which coincides with a light minimum for all the visible or near-ultraviolet colours (and also with a minimum of $B-V$, $b-y$ and m_1, and a maximum of c_1).

Mean curves drawn among the points show ranges of about 0.028, 0.101, 0.230 and 0.059 mag. respectively for y, b, v and u. A secondary minimum appears in b and mainly in v. It seems to be even deeper in B, but this may be a consequence of the larger observational errors of the old measurements.

The variety of the ranges and the shapes of the curves confirm the conclusion previously reported (Renson 1991) that the variations of VV Scl do not originate from eclipses. This variety in ranges is typical of the light variations among Ap stars. The remarkably large amplitude in B, combined with a bad period determination led to a wrong classification.

The light curves can be approximated by a limited Fourier series. The approximation is written

Table 1. Parameters of the least-squares fits of the lightcurves

Filter	A_1	A_2	A_3	A_4	ϕ_1	ϕ_2	ϕ_3	ϕ_4	σ
u	0.0253	0.0080	0.0027	0.0006	5.4091	4.9637	4.3352	5.2234	0.0044
v	0.0794	0.0621	0.0072	0.0027	5.5031	5.0974	4.4727	4.4708	0.0026
b	0.0428	0.0217	0.0028	0.0010	5.5591	5.0834	4.5318	4.8920	0.0023
y	0.0136	0.0028	0.0008	0.0003	5.8800	5.2854	4.6519	2.5868	0.0023

$$m = A_0 + \sum_{i=1}^{n} A_i \cos\left(\frac{2\pi i\,(t - t_0)}{P} + \phi_i\right) \tag{1}$$

where m is the magnitude, P the period ($5\overset{\mathrm{d}}{.}0976$), t the time and t_0 the origin of time (2 448 281.0). Table 1 gives the parameters of a 4-sine fit. The second-harmonic component (A_2) is very strong in b and v, while the fundamental component dominates the y and u light curves. The amplitudes A_3 amount to about one tenth of A_1 at each wavelength. The phases are coherent: ϕ_1, ϕ_2 and ϕ_3 increase only slightly from u to y. The fourth harmonics appears to be much less meaningful, with rather random phases. The colour index c_1 shows a phase shift of π in all three components. The mean residuals σ are remarkably low, often below .003 mag. They give reliable estimates of the quality of the SAT observations in the LTPV programme. They also show that more than two sines are needed to accurately fit Ap-star light curves. The same conclusion was already reached for other stars (see, e.g., Manfroid & Renson 1989 for HD 29009 = 46 Eri, and Manfroid & Renson 1992 for HD 41089 = TW Col).

4. Comparison with other Ap stars

The amplitude of the variations of VV Scl is particularly large in v. Another Ap star for which the v variation range is very large is GC 17353 = BR Cru (Renson 1978): 0.24 mag. compared to 0.23 here. These are the two largest ranges ever observed in v among Ap stars. In BR Cru, however, y and v vary in opposite directions, while the range of the b variation is almost zero ("null wave-length"). It is noteworthy that the spectral type of that star is A5:p Cr, i.e., similar to that of VV Scl.

Most often the amplitude of the light variations in Ap stars are of a few per cent. But variations larger than 0.1 mag. have been found for some of them. Table 2 lists Ap stars that have been observed in the *ubvy* system and for which the variation range is larger than 0.1 mag. in at least one of the four colours (references may be found in the catalogue compiled by Catalano and Renson, 1984, 1988). A correction has been introduced in the ranges of HD 29305 and HD 57946 to take account of the dilution of the luminosity variations by the light of the close companion. Some other Ap stars, which have not been observed in the *uvby* system, exhibit also large variations, namely HD 51418 = NY Aur (sp. type A0p HoDyEuSrCr) which has a variation range of 0.16 mag. in the V band of the Johnson system (Gulliver & Winzer 1973), HD 98457 = LS Hya (sp. type A0p Si) and HD 191287 = AR Cap (sp. type B9p Eu or Si) observed in the Geneva system and showing variations of respectively 0.12 and 0.2 mag. in the V band and exceeding 0.2 mag. in U for both stars (Waelkens 1985).

In the c_1 index the largest variations are displayed by BR Cru (0.45), HD 125630 (0.34), HD 7676 (0.32), HD 221568 (0.30).

Generally for Ap stars the variation in u is larger than in v (and also larger than in y and b). But there are exceptions. Besides some cases appearing in Table 2, among which the most conspicuous ones are HD 7676, BR Cru, HD 119213, HD 125630 and HD 221568, let us also cite HD 98088 = SV Crt (A8p SrCrEu), HD 137909 = β CrB (A9p SrEuCr), HD 71866 = TZ Lyn (A1p EuSrSi) and HD 24712 = DO Eri (A9p SrEuCr). Note that each of these stars has a spectral type later than A0.

Table 2. Ap stars with variation ranges larger than 0.1 mag, in at least one of the four colours y, v, b, u.

Star	range> 0.1 mag in	spectral type
HD 7676 = VV Scl	b, v^{**}	A5 SrCrEu
HD 10840 = BM Hyi	u	B9 Si
HD 22470 = 20 Eri	u	B9 Si
HD 24155 = V766 Tau	u	B9 Si
HD 28843 = DZ Eri	b, v, u^{*}	B9 Hewk.
HD 29305 = α Dor	u^{*}	A0 Si
HD 30849 = SY Pic	v	A5 SrEuCr
HD 32549 = 11 Ori	u	B9 SiCr
HD 32966 = TU Lep	y, b, v^{*}, u^{*}	B9 Si
HD 53116 = V646 Mon	u	A0 SrEu
HD 57946 = CoD−36°3554	u^{**}	B8 Si
HD 96910 = CoD−47°6547	v	B9 SiCrEu
GC 17353 = BR Cru	v^{**}	A5 Cr
HD 116890 = EZ Mus	u	B9 Si
HD 119213 = CQ UMa	v	A3 SrCr
HD 124224 = CU Vir	u	B9 Si
HD 125248 = CS Vir	v	A1 EuCr
HD 125630 = BS Cir	y, v^{*}	A2 SiCrSr
HD 187473 = V4064 Sgr	y, u^{**}	B9 EuSrSi
HD 199728 = 20 Cap	u	B9 Si
HD 206653 = BC Ind	u	B9 Si
HD 215441 = GL Lac	y, b^{*}, v^{*}, u^{**}	B9 Si
HD 221006 = CG Tuc	u	A0 Si
HD 221568 = V436 Cas	y^{*}, v^{*}	A1 SrCrEu

*: range $\geq$ 0.15 mag.; **: range $\geq$ 0.2 mag.

The only exception to this rule is HD 96910; but the type of this 8th mag. star is not very sure, the only determination being that of the HD catalogue.

It has long ago been noted that many well known Ap stars are bluer at the minimum light (Renson 1963, Ledoux & Renson 1966), suggesting that the change in apparent surface is more important than the temperature change in determining the luminosity variation. This idea was recently revived (Böhm-Vitense & Van Dyk 1987) on the basis of far ultraviolet observations.

However, as shown by the generally larger variations in the near ultraviolet, and by the above-mentioned correlation of this with the spectral type, variations due to line absorption must play an important part and are to be taken into account in theoretical models. From this standpoint the study of stars in Table 2 may be most useful. In particular BR Cru and HD 7676 lose more than 20 % of their light in v between the maximum and the minimum.

Another contribution of this study of HD 7676 is the confirmation of the correlation of the period with the spectral type. It is well known that there is a great diversity of periods among Ap stars, with a maximum near 2 d (Renson 1965, see also Fig. 1 of Hensberge et al. 1983), but a slight correlation with the spectral type had already been put forward even when only a few periods were known (Renson 1969, Fig. 38): on the average the periods are longer for Ap stars having later types. This correlation is confirmed by the period determinations made since then. It is clearly visible when all known periods are put preferably in a logarithmic scale for each spectral sub-class. It is especially conspicuous for the sub-classes B8 to A2, where Ap stars with known periods are numerous. Moreover for types earlier than B8 most periods are shorter than 2 d, while for types later than A2 most periods are longer than 2 d. With its longer period and its later spectral type, HD 7676 agrees with the observed correlation.

Acknowledgements. The authors are greatly indebted to the observers of the Long-Term Photometry of Variables project at ESO for their most important contributions.

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