LONG-TERM OPTICAL PHOTOMETRY OF THE DWARF NOVA VW HYI*

S. F. VAN AMERONGEN and J. VAN PARADIJS
Astronomical Institute 'Anton Pannekoek', University of Amsterdam, Amsterdam, The Netherlands

ABSTRACT. Long-term five-colour photometry of the dwarf nova VW Hyi shows no evidence for a secular change of the flux during the quiescent interval between normal outbursts (3σ upper limits between 0.16 and 0.20 mag in the five passbands). However, the amplitudes in the orbital B-U and U-W colour curves change during quiescence. A delay in the progress of normal outbursts toward higher frequencies confirms the delay, seen with IUE, in the onset of a normal outburst toward higher frequencies. Just after outburst, the system is substantially bluer than later in quiescence.

1. INTRODUCTION

In dwarf novae the accretion onto the white dwarf of matter transferred from the red secondary star does not proceed in a regular way. Long periods of quiescence are interrupted by outbursts, as the accretion rate onto the white dwarf suddenly increases. The optical brightness then typically increases by ~3-5 mag.

Two models have been proposed for this irregular variation of the accretion rate. In the mass-transfer-instability model [2] the outburst is caused by a sudden increase in the mass-transfer rate from the secondary star. In the disk-instability model [3,8,9,10] the mass-transfer rate from the secondary is more or less constant, but the accretion disk undergoes a limit cycle with states of high and low mass-transfer rates.

These two models predict a different behaviour of the accretion disk in quiescence. In the disk-instability model a slowly rising flux from the disk is expected, as matter from the secondary star is stored in the disk increasing its surface density, whereas in the mass-

* Based on observations made at the European Southern Observatory, La Silla, Chile

Paper presented at the IAU Colloquium No. 93 on 'Cataclysmic Variables. Recent Multi-Frequency Observations and Theoretical Developments', held at Dr. Remeis-Sternwarte Bamberg, F.R.G., 16–19 June, 1986.

Astrophysics and Space Science **130** (1987) 127–134.

transfer-instability model a steady or perhaps slowly declining flux is expected.

Therefore a long-term optical study was made as part of a multi-wavelength campaign of the bright dwarf nova VW Hyi [11,12,14,15,16]. This system undergoes outbursts every 20-30 days, lasting for about 3-5 days. At outburst maximum it reaches a brightness V≃9.5. Every ~180 days VW Hyi undergoes a superoutburst that lasts for 10-14 days and reaches a peak brightness V≃8.5.

2. OBSERVATIONS

VW Hyi was observed from July 19 to November 4, 1984 during 42 nights with the Walraven photometer on the 90 cm light collector at ESO. Simultaneous measurements in five passbands are obtained between ~3250 and ~5400 Å [5,13]. An overview of the observations in the B band is given in Fig. 1.

The source was monitored quasi-continuously, together with two local comparison stars, CPD -71°250 and CPD -71°252, and reduced differentially with respect to the latter.

An absolute flux calibration was obtained by a comparison of these stars with the Walraven standard stars [6]. We express the fluxes in units milliJansky (1 mJy = 10^{-26} erg cm^{-2} s^{-1} Hz^{-1}).

VW Hyi underwent six outbursts during the observations, that peaked at (JD-2445000) 899, 923, 949.5, 965, 981 and 996.5 . These times of maximum brightness were provided by the observers of the Variable Star Section of the Royal Astronomical Society of New Zealand [1]. The last outburst preceded the superoutburst that peaked at JD 2445999 [12].

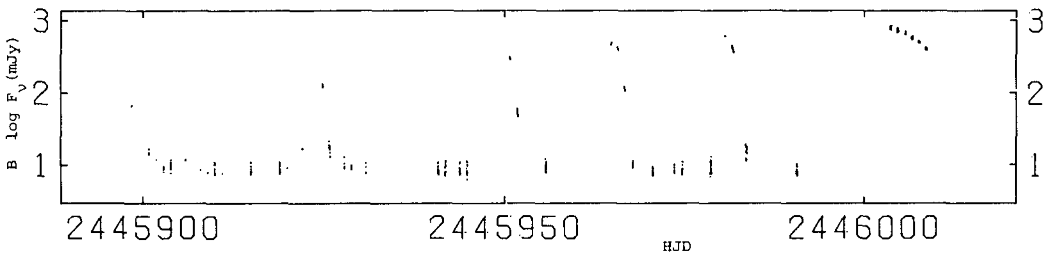

Fig. 1. Overview of the observed flux in the Walraven B band of VW Hyi, from 1984 July 19 (JD 2445900) till November 4 (JD 2446008).

3. OUTBURSTS

The outbursts near JD 2445965 and 2445981 were observed both during the rise and the decline (see Fig. 2). It is apparent that both during the rise and the initial decline the rates of change of the fluxes depend on wavelength, such that toward shorter wavelengths outburst maximum is reached later. Delays in time of maximum brightness, in the W band with

https://doi.org/10.1017/S0252921100104750 Published online by Cambridge University Press

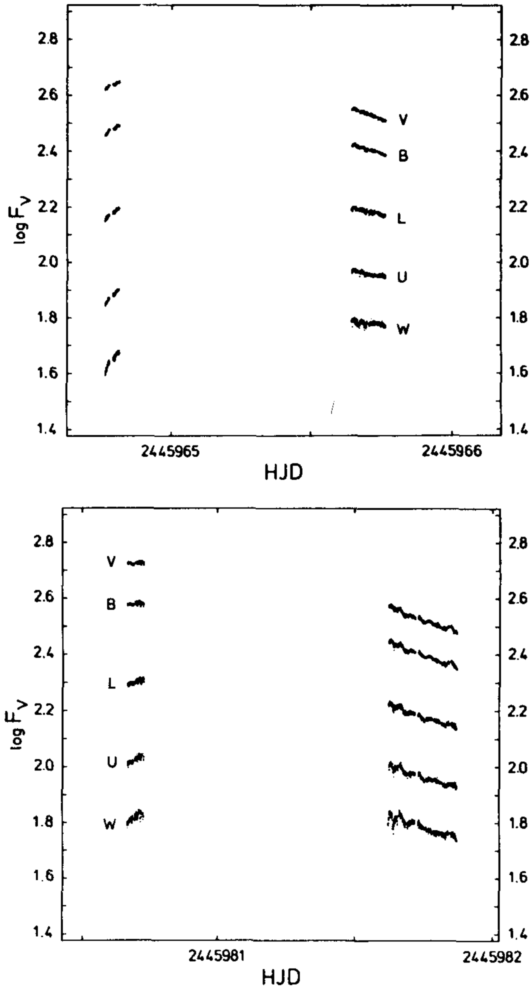

Fig. 2. Overview of the normal outbursts of VW Hyi near JD 2445965 and 2445981, close to outburst maximum. The flux scale is for V band only, the light curves in the B, L, U and W bands are shifted downward successively by 0.2.

respect to the V band, are approximately 8 and 13 hours respectively for these two outbursts.

Interleaving both Walraven and IUE spectral energy distributions during rise and decline for the outbursts near JD 2445965 and 2445981 (see Fig. 3 [14,16]) we find that the progressive delay toward higher frequencies of the onset and maximum of the outburst extends over the combined spectral ranges. It is also apparent that during decline the overall spectral shape is bluer than in quiescence.

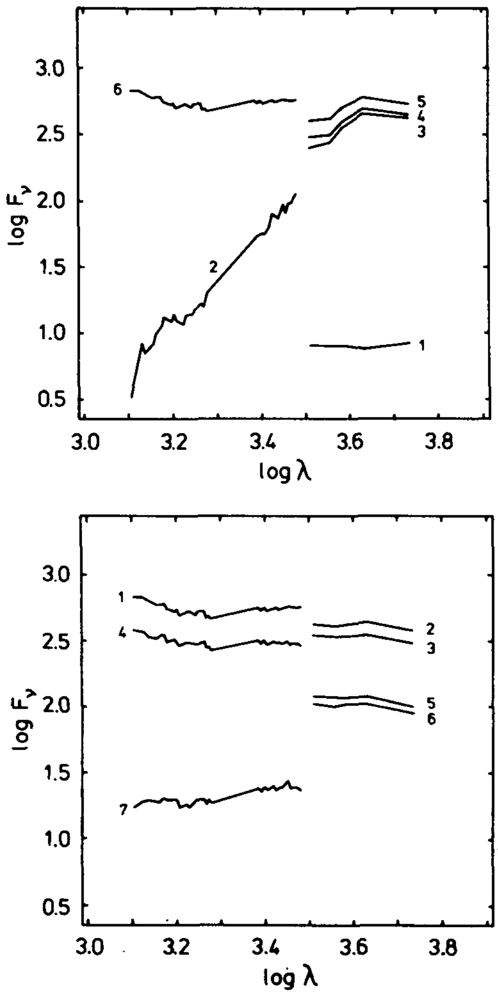

Fig. 3. Spectral energy distributions of VW Hyi, during the outbursts near JD 2445965 and 2445981, during the rise (top) and the decline (bottom) separately, combining Walraven and IUE data [16]. Numbers indicate a (non-scaled) chronological order. Numbers 3 and 4 (top) and numbers 5 and 6 (bottom) are from the outburst near JD 2445965.

4. QUIESCENCE

4.1. Orbital light curves

From our observations during the quiescent state we obtained 22 times of maximum light, which together with 73 previously published values [4,7,17,18], yield an updated linear orbital ephemeris

$$HJD_{max} = \underset{\pm 59}{2440128.02407} + \underset{\pm 14}{0.074271038}\,E$$

https://doi.org/10.1017/S0252921100104750 Published online by Cambridge University Press

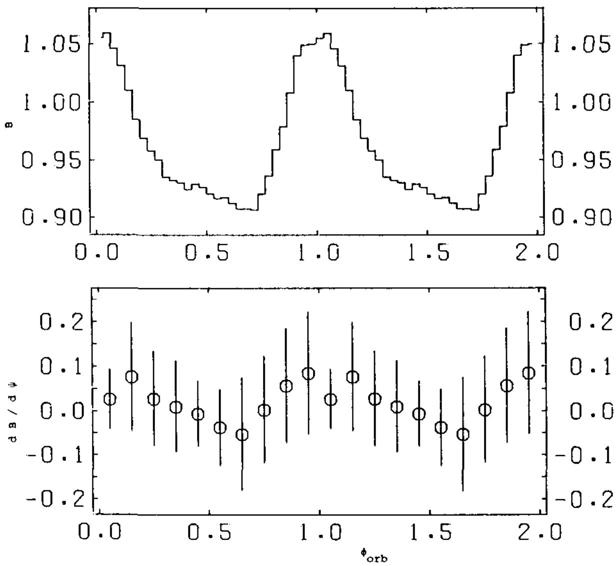

Fig. 4. a) Average quiescent orbital light curve of VW Hyi in the B band. The flux is given as 2.5× log F_ν, for convenience. b) Slopes (d log F_ν/dt) of (assumed) linear relations between the B band flux and inter-outburst phase ψ, in ten orbital phase intervals.

By folding all quiescence data with this ephemeris (and applying zero-point shifts for data obtained during each night) average orbital light curves were obtained. An example of these average light curves is shown in Fig. 4a; its main feature is an asymmetric hump, which is due to a bright spot, formed where the stream of matter from the secondary star hits the outer edge of the accretion disk.

4.2. Secular changes

In our search for secular trends in the properties of VW Hyi through quiescence, we have used as a temporal parameter the inter-outburst phase ψ, defined by $\psi=(t-T_{i-1})/(T_i-T_{i-1})$, where T_i is the time of maximum brightness in outburst i.

4.2.1. Average flux

In Fig. 5 we show as a function of ψ the average residual flux (per night) relative to the average orbital light curve. It appears that for some days after outburst ($\psi\approx0.1-0.3$) the flux is still slowly declining. In order to avoid any influence from outbursts, we have excluded data with $\psi<0.25$ in our search for possible secular trends through quiescence. After $\psi=0.25$ no secular changes are apparent in the average flux (3σ upper limits between 0.16 and 0.20 mag in the five passbands).

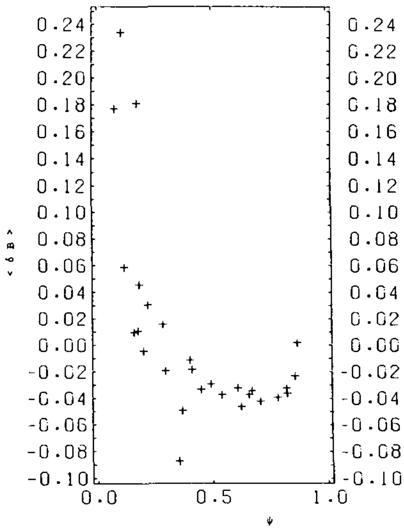

Fig. 5. Average residual flux (per night) in the B band relative to the average orbital light curve, as a function of inter-outburst phase ψ.

4.2.2. Light curves

In order to look for possible secular changes in the shape of the orbital light curves, the data have been averaged in orbital phase intervals, each 0.1 cycle wide. We made linear least-squares fits to the averaged data in these orbital phase intervals. The slopes of these linear fits in ten orbital phase intervals are shown in Fig. 4b. It is apparent that in none of the orbital phase intervals significant changes are found. There is a slight suggestion in Fig. 4 that the slopes smoothly follow the average orbital light curves, indicating that a secular increase of the hump amplitude might be present.

4.3. Colours

4.3.1. Orbital colour curves

In Fig. 6a the average orbital B-U colour curve is shown. This curve follows the average light curves, indicating that the average hump amplitude (orbital maximum light - orbital minimum light) is largest in the B band (0.373 ± 0.009 mag), as is also apparent from the individual light curves for the five passbands.

4.3.2. Average colours

Just after outburst (ψ<0.25) VW Hyi is substantially bluer in B-U (across the Balmer jump) by ~0.09 mag, than later in quiescence (Fig. 7). No such changes are apparent in the other colours.

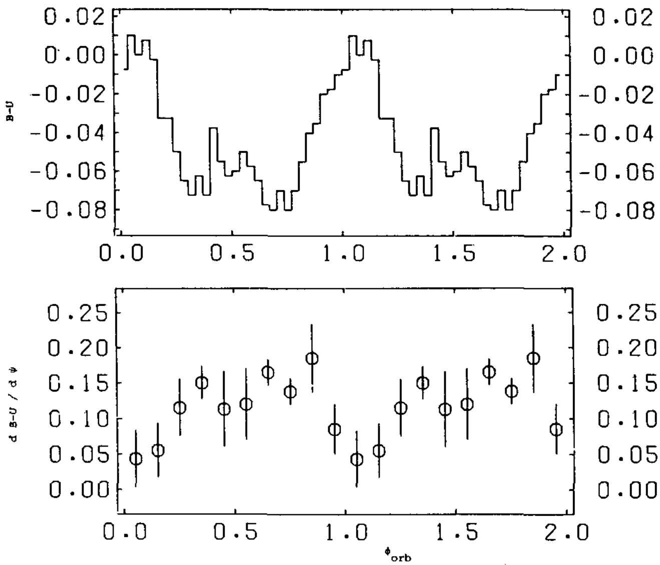

Fig. 6. Same as figure 4, for the B-U colour.

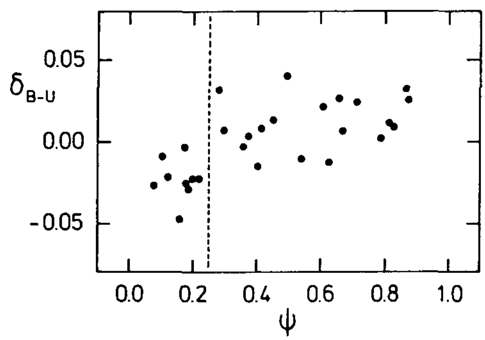

Fig. 7. Variation with inter-outburst phase ψ of the average B-U colour per night, after correction for the average orbital colour modulation.

4.3.3. Changes in the colour curves

Changes in the colours, in ten separate orbital phase intervals, have been calculated in the same way as for the fluxes (sec. 4.2.2.). The results are shown in Fig. 6b for B-U. The changes appear to be more significant than for the individual B and U fluxes, indicating that an important source of scatter in the data, erratic variations on timescales of minutes to days, is coherent in these passbands.

It is apparent from Fig. 6b that the rates of change in B-U are anti-correlated with the average B-U colour curve. This shows that the amplitude in the B-U curve decreases by 0.08 ± 0.02 mag in the last three quarters of quiescence. (The average amplitude is 0.083 ± 0.009 mag.) Although no orbital modulation is visible in the average U-W colour curve, the slopes of U-W with ψ have a smooth orbital modulation with maximal changes at orbital minimum and maximum light. The amplitude of the orbital U-W curve increases by 0.14 ± 0.05 mag through the last three quarters of quiescence.

5. CONCLUSIONS

From a long-term photometric study of the dwarf nova VW Hyi we find no evidence for a secular change between outbursts of the average brightness of this system. There is evidence for secular changes in the amplitudes of the orbital B-U (across the Balmer jump) and U-W (on the ultraviolet side of the Balmer jump) curves. The B-U amplitude decreases by 0.08 ± 0.02 mag, the U-W amplitude increases by 0.14 ± 0.05 mag.

The average orbital colour curves smoothly follow the average light curves. The significant changes in the amplitudes of the B-U and U-W colour curves do not show up significantly in the individual light curves. It appears that this is the result of erratic variations on timescales of minutes to days which are coherent in the five passbands.

The delay toward higher frequencies of the onset to outburst, the progress in outburst rise and the initial outburst decline extends over the spectral region covering ~1200 to ~6500 Å.

6. REFERENCES

[1] Bateson, F.M., 1985. Publ. Var. Star Section of the Roy. astr. Soc. New Zealand, **12**, 103.
[2] Bath, G.T., 1975. Monthly Not. R. Astr. Soc., **171**, 311.
[3] Faulkner, J., Lin, D.N.C. & Papaloizou, J., 1983. Monthly Not. R. astr. Soc., **205**, 359.
[4] Haefner, R., Schoembs, R. & Vogt, N., 1979. Astr. Astroph., **77**, 7.
[5] Lub, J. & Pel, J.W., 1977. Astr. Astroph., **54**, 137.
[6] Lub, J. & Pel, J.W., 1985. private communication.
[7] Marino, B.F. & Walker, W.S.G., 1974. Inf. Bull. Variable Stars, No. 864.
[8] Meyer, F. & Meyer-Hofmeister, E., 1981. Astr. Astroph., **104**, L10.
[9] Meyer, F. & Meyer-Hofmeister, E., 1982. Astr. Astroph., **106**, 34.
[10] Papaloizou, J.C.B., Faulkner, J. & Lin, D.N.C., 1983. Monthly Not. R. astr. Soc., **205**, 487.
[11] Polidan, R.S. & Holberg, J.B., 1986. Monthly Not. R. astr. Soc., submitted.
[12] Pringle, J.E., Bateson, F.M., Hassall, B.J.M., Heise, J., Holberg, J.B., Polidan, R.S., Van Amerongen, S.F., Van der Woerd, H., Van Paradijs, J. & Verbunt, F., 1986. Monthly Not. R. astr. Soc., submitted.
[13] Rijf, R., Tinbergen, J. & Walraven, Th., 1969. Bull. Astron. Inst. Neth., **20**, 279.
[14] Van Amerongen, S.F., Damen, E., Groot, M., Kraakman, H. & Van Paradijs, J., 1986. Monthly Not. R. astr. Soc., submitted.
[15] Van der Woerd, H. & Heise, J., 1986. Monthly Not. R. astr. Soc., submitted.
[16] Verbunt, F., Hassall, B.J.M., Marang, F., Pringle, J.E. & Warner, B. 1986. Monthly Not. R. astr. Soc., submitted.
[17] Vogt, N., 1974. Astr. Astroph., **36**, 369.
[18] Warner, B., 1975. Monthly Not. R. astr. Soc., **170**, 219.