ASPECTS OF VW HYI

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Summary

A coherent sinusoidal oscillation of approximately 88 s and $0\overset{m}{.}005$ amplitude has been detected at the end of the long eruption of VW Hyi in December 1975. The phenomenon was observed during five nights, when the period varied between 90 and 87 s. Some runs indicate that the amplitude depends on the phase of the orbital revolution. This result favours models in which oscillations are caused by rotation of inhomogeneities in the inner disc.

A model is proposed to explain the periodic light variations with a 3 % longer period than the orbital period of VW Hyi during long eruptions by a sudden and short reverse transport of matter from the inner parts of the accretion disc. The material impacts on a limited area in higher latitude at the red component producing a second hot spot. Differential rotation and motion to lower latitudes could simulate the behaviour of the observed periodic light variations. Some crude energy calculations result in acceptable parameters.

Introduction

VW Hyi, one of the well observed dwarf novae, is a particularly interesting object since two types of outbursts, long and short eruptions, the longer one showing periodic light variations, and high frequency oscillations have been detected.

Some basic data and the photometric behaviour during a long eruption are shown in Fig. 1. During normal light the typical "hot-spot"-hump of around 40 % relative amplitude can be seen covering 50 % of the orbital period P_o. The absolute amplitude of the hump remains almost constant during short eruptions and at the beginning of long eruptions. Just before light maximum of a long eruption no distinct feature was detected in the light curve, but after starting observations

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again after 21 hours the known periodic humps had already evolved to 35 % (Haefner et al., in preparation). The absolute amplitude of these humps decreased somewhat faster than the mean brightness of

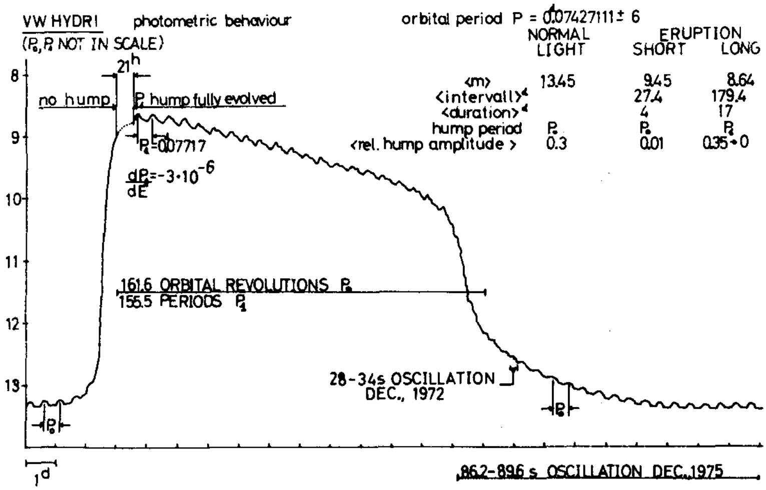

Fig. 1. Photometric behaviour of VW Hyi

the object. Their shape is asymmetrical with a steep rise and a flat decline covering the remaining part of the period. In the course of the long eruption secondary hump structures evolve which move in phase with respect to the main hump (Vogt, 1974). A still very puzzling fact is that the period P_1 of these humps is about 3 % longer than the orbital period. Furthermore, P_1 is of far less stability than P_o. It decreases appreciably, but does not reach P_o during the long eruption. Within 12 days of the outburst approximately six more orbital revolutions than P_1 humps take place. Warner (1974a) detected high frequency oscillations in the range of 28 to 34 s with 1 % amplitude at the steep decline of a long eruption lasting at least four hours. We found oscillations of about three times that period existing in five nights at the end of another long eruption.

Observations and Reduction

High speed photometric observations of VW Hyi have been performed by Haefner et al. in December 1974 and Vogt in December 1975 respectively covering the beginning and end of a long eruption. This paper reports on some results obtained from these observations. A more complete analysis will be published elsewhere. In Table 1 the observational data for December 1975 are compiled.

Table 1. Observational data and results

Date: 1975 Dec	Run	Start (UT)	Duration (s)	Mean B-magnitude	Period (s)
21./22.	1	$1^h35^m34^s$	8190	10.5	-
	2	4 10 49	8805	10.6	89.6 *)
22./23.	1	1 05 30	10110	12.3	87.6 *)
	2	4 13 16	8805	12.5	-
23./24.	1	1 05 34	11400	13.3	88.2
	2	4 32 34	13440	13.3	88.4, 86.8, 86.0
24./25.	1	1 12 49	8775	13.5	88.5
25./26.	1	1 11 31	5340	13.7	-
	2	2 41 11	7845	13.7	88.0, 86.9
26./27.	1	1 31 26	5940	13.6	87.6, 86.2
	2	3 11 19	5100	13.6	87.8
29./30.	1	1 18 30	7425	13.7	88.0
31./1.	1	1 42 11	10590	13.7	-

*) low signal to noise ratio

Results

A period of about 88 s appeared in most of the power spectra of the photometric runs obtained in December 1975. Therefore, periodograms in the region of 70 to 100 s were computed. The periods are listed in Table 1 (column 6). Sometimes multiple periods appear, but the analysis of sections of such runs indicates that they are confined to separate time intervals. The lifetime of single periods reaches the order of hours. Fig. 2 shows a typical periodogram with the stellar oscillation at 88.5 s and a calibration peak at 74 s. The characteristic shape of the oscillation was determined by averaging over a time interval of three periods. Fig. 3, as an example, demonstrates the sinusoidal shape of the oscillations. This result is confirmed as well by the power spectra, where only the power of the fundamental period could be detected.

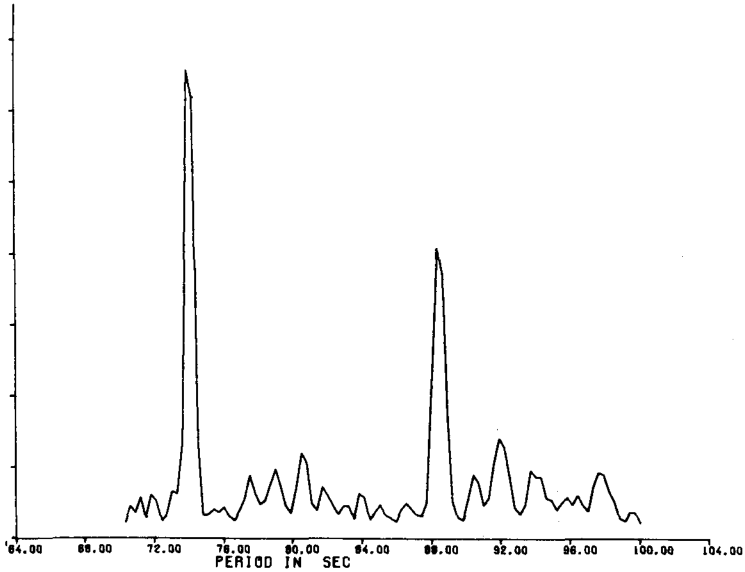

Fig. 2. Periodogram showing the oscillation of VW Hyi near 88 s and a calibration peak at 74 s

An original light curve showing two normal humps together with two numerically filtered light curves is given in Fig. 4. The two numerical filters were chosen to have equal bandwidth but different center frequencies, only the first filter containing the oscillation period. The difference in coherency is clearly demonstrated. In some of the longer runs, one of them is shown in Fig. 4, there are indications that the amplitude is enhanced just before and lowered just after hump maximum. The long-time behaviour of the oscillation period is shown in Fig. 5. Since the error of the periods is less than 0.3 s, definitive period changes occurred, but no concrete tendency is indicated.

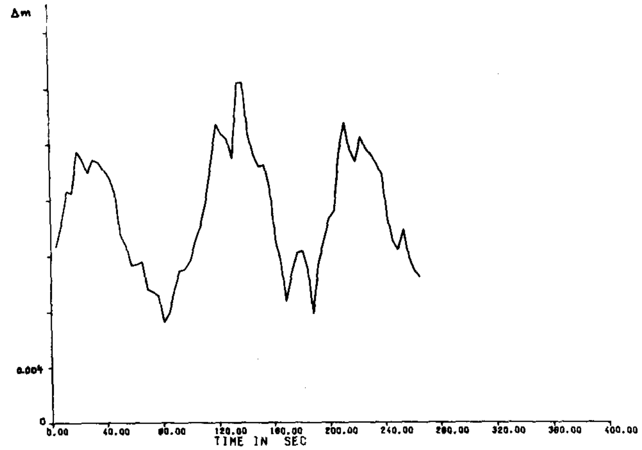

Fig. 3. Light curve averaged for a time interval of three oscillation periods (265.5 s) showing the sinusoidal shape of the light variation.

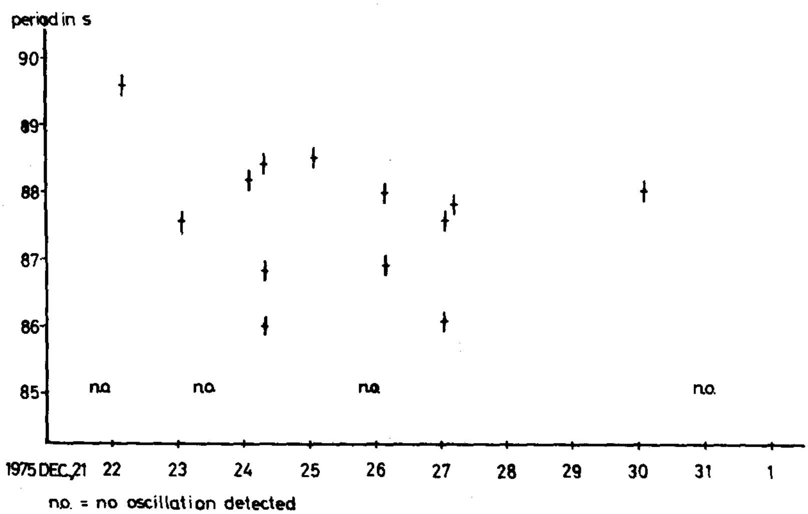

Fig. 5. Long time behaviour of the oscillation period of VW Hyi.

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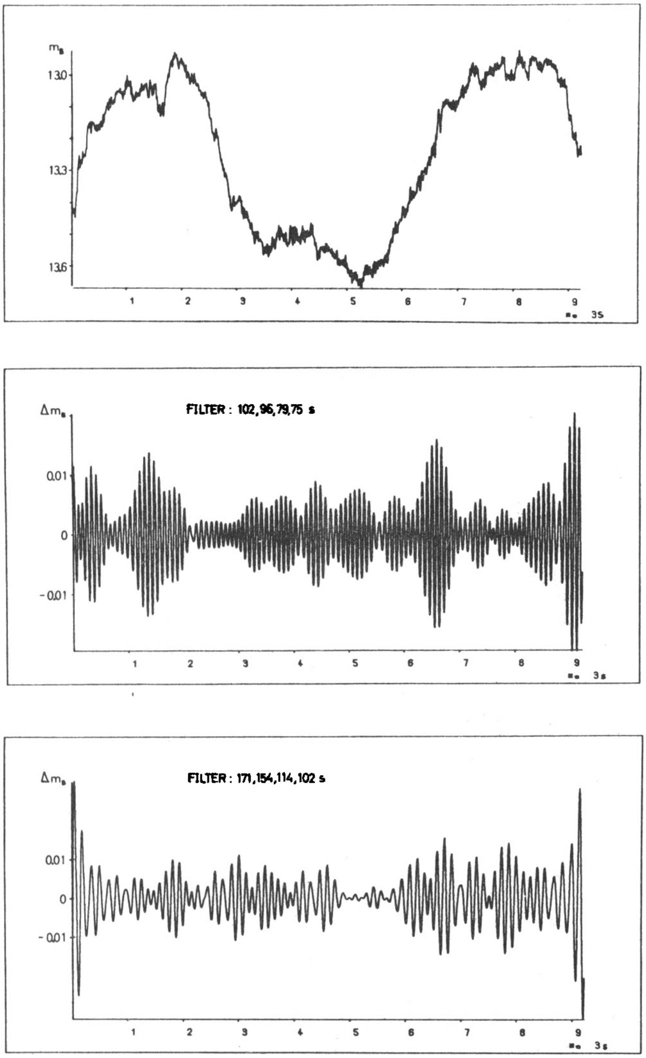

Fig. 4. a) Original light curve of run 1 1975 Dec. 23/24. b) Filtered light curve of a) with a filter passing the oscillation period of VW Hyi. c) Filtered light curve of a) with a filter not passing the oscillation period of VW Hyi. The difference in coherency between b and c is clearly shown, furthermore there is an indication that the oscillation is enhanced before and lowered after hump maximum. The strong oscillation at the beginning and end of the run is a numerical effect.

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Discussion

Most periodic oscillations detected for cataclysmic variables cover the range of 10 to 35 s. Only for two objects, DQ Her (Herbst et al., 1977) and RU Peg (Patterson, 1977), longer periods are reported. However, the coherency of the oscillations is much higher for the first and much lower for the second object, so that the physical processes should be different from those of the 88 s period. According to the time dependent behaviour, the 88 s period seems to belong to the group of oscillations first mentioned. Assuming that there is a common physical origin, difficulties arise to explain this by non-radial pulsations of the white dwarf. The oscillations might be more easily interpreted in terms of inhomogeneities in different layers of the differentially rotating disc. In this case, however, the question arises why so many periods accumulate in the region of 10 to 30 s and do not spread to higher values.

Another property of VW Hyi, the occurrence of the P_1 humps, may be linked to instabilities of the disc. A fundamental problem is to find an apt position for the radiation source capable to represent the phenomenon P_1. Warner (1975) proposed a spot on the secondary for which he assumed non-synchronized retrograd rotation. But since P_1 varies quite rapidly, it can hardly be related directly to the rotation of the secondary. If the spot would be located in reasonable distance from the equatorial plane on the red component, moving to lower latitude, and if the secondary rotates differentially (with either synchronized or at least more synchronized rotation at the equator than at higher latitudes), the observed behaviour of the P_1 structures in the light curve can be explained. Partial destruction of the spot due to differential rotation might lead to the observed secondary structures in the hump profiles. The dilution effect would not be too strong since only about six revolutions relative to the corotating frame of the system take place during a long eruption. According to observations of eclipses of Z Cha performed by Warner (1974b), the long eruption mainly affects the inner region of the disc. Therefore it might be assumed that the P_1 spot is produced by matter which is ejected from the inner disc at the beginning of a long eruption. The equatorial region of the secondary remains almost undisturbed since matter accelerated in the disc plane is stopped by the outer layers. No indications have been found that large amounts of matter leave the system after an outburst. This suggests ejection velocities not exceeding some 100 km/s. Therefore matter reaches the secondary through two narrow channels only. Computations of Kepler trajectories show that the impact area on the red component is quite limited. Due to the orientation of VW Hyi only one of the two spots, which are located symmetrically to the equator, can be seen.

This scenario may be checked by some calculations, which are necessarily very crude according to the low accuracy of the fundamental system parameters. Since no relevant color variations were detected during the P_1 hump at the beginning of an outburst, the temperature T_s of the spot on the secondary is assumed to be equal to the main radiation source, presumably the inner disc. $T_s = 1.9 \times 10^4$K (Holm et al., 1974). At maximum light the relative radiation of the P_1 spot is estimated to be 15 %. The projected radiating areas of spot and disc should then be of the same ratio. The mean radiation of the P_1 spot during the total time of eruption is around 5 % of the outburst radiation. For an outburst of dwarf novae the luminosity is estimated to be around 16 $L_\odot$ (Warner 1976). Due to its short period VW Hyi may be fainter. Therefore one obtains for the luminosity of the P_1 spot $L_s = 3 \times 10^{33}$erg/s. The lifetime of the P_1 spot is around 10^6s, therefore its radiated energy amounts to $E_s = 3 \times 10^{39}$erg. The area of the spot can be estimated to $F_s = L_s T^{-4} \sigma^{-1} = 4 \times 10^{20}$cm^2 and the radius (if circular) to $R_s = 1.16 \times 10^{10}$cm. Using the period radius relation (Warner, 1976) we obtain for the radius of the (circular) secondary $R_2 = 1.37 \times 10^{10}$cm. R_s is quite high, but considering the low accuracy of the basic parameters, it seems acceptable. In order to store $E_s = 3 \times 10^{39}$erg at 19000 K, the mass of $1/3\ m_H E_s k^{-1} T^{-1} = 6.7 \times 10^{26}$gm $= 3.4 \times 10^{-7} M_\odot$ is necessary. Since the temperature at impact is approximately twice that value, it seems realistic that only 1/4 of this material comes from the disc. The impact velocity would then be around 30 km/s, assuming 0.5 for the conversion factor of kinetic to thermal energy.

It might be considered as a problem that no radial velocity changes have been detected during outbursts. However, if the inclination of the system is not so that one looks at the edge of the disc, the expanding material will produce broadened lines which cannot be resolved in spectra of quality attainable for objects as faint as VW Hyi. Another spectral feature may be searched for to test the assumptions. The P_1 spot produces narrow hydrogen absorption lines which move with inverse phase relatively to the broad disc-absorption lines. The narrow lines arise simultaneously with the P_1 hump. A crucial test could be made obtaining high quality spectra of appropriate time resolution.

The motion of the P_1 spot on the secondary may be considered finally. The rotation period of the P_1 spot in the corotating system frame shall be denoted by P_s and the corresponding frequency by $\omega_s = 2\pi/P_s$; $P_2(\varphi)$ and $\omega_2(\varphi)$ shall define the rotational field on the secondary's surface in the system frame (φ = latitude).

One obtains the following relations:

$$\omega_0 = 2\pi/P_0\,;\quad \omega_1 = 2\pi/P_1\,;\quad \omega_s = \omega_1 - \omega_0 = \omega_2(\varphi_s(t));$$
$$d\omega_s/dt = d\omega_1/dt = (\partial\omega_2/\partial\varphi)(\partial\varphi_s/\partial t) = -2\pi P_1^{-2} dP_1/dt\,;$$

$\partial\omega_2/\partial\varphi$ represents the differential rotation and $\partial\varphi_s/\partial t$ the motion in latitude of the light center of the P_1 spot. Assuming synchronized rotation at the equator, linear dependence of ω_2 on φ and that the P_1 spot originates around $\varphi = 45^\circ$ one can estimate $\partial\varphi_s/\partial t = (d\omega_s/dt)/(\partial\omega_2/\partial\varphi)$. Since $\partial\omega_2/\partial\varphi = 2\pi/(P_s \cdot 45)$ one obtains $\partial\varphi_s/\partial t = -45\,P_s\,\dot{P}_1/P_1^2 = -0.64$ ($^\circ$/d) as a crude estimate for the polar motion of P_1. In this case $\partial\omega_2/\partial\varphi$ is relatively high and therefore the P_1 spot will be distorted strongly in the course of the long eruption. This might suggest that the secondary is in retrograd rotation at the equator, but more synchronized than in higher latitudes resulting in a lower $\partial\omega_2/\partial\varphi$ but a higher $\partial\varphi_s/\partial t$. Even for a relatively extended P_1 spot one can find reasonable parameters for $\omega_2(\varphi)$ and $\partial\varphi_s/\partial t$ to represent the period P_1.

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