Long-term optical studies of cataclysmic variables

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Spin-up of the white dwarf in the intermediate polar AO Psc/H2252–035*

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Summary. Walraven photometric observations made in 1983 and 1984 of the intermediate polar AO Psc/H2252–035 are used to derive new times of maximum light for its orbital and pulsational light curves. Combining these times with previously published values we find that the periods of both pulsations show a secular decrease. The spin-up rate $\dot{P}$ of the white dwarf equals $\dot{P}=-6.6\pm1.0\times10^{-11}$. This result is in good agreement with the value predicted by Lamb & Patterson for an accreting magnetized white dwarf, spinning near its equilibrium period. However, the inferred low value of the magnetic field of the white dwarf is in conflict with the conclusion of King, Frank & Ritter that there is no systematic difference between the white-dwarf magnetic fields in AM Her-type systems and intermediate polars.

1 Introduction

The polars and intermediate polars are distinct subgroups of cataclysmic variables, whose X-ray and optical properties are strongly influenced by the large magnetic field strength of the mass-accreting white dwarf. In the polars (AM Her-type systems) the Alfven radius of the white dwarf is comparable to the orbital separation, and the interaction of the white dwarf's magnetic field with the secondary star has forced the white dwarf to corotate with the orbital period. Also the formation of an accretion disc, which is prominent in the 'normal' cataclysmic variables, is inhibited, as the matter shed by the secondary is forced to flow along the white dwarf's magnetic field lines.

In the intermediate polars the magnetic interaction between the white dwarf and the secondary star is weaker, most probably because of their generally larger orbital period, and therefore orbital separations (Chanmugam & Ray 1984; King, Frank & Ritter 1985). As a result of this the white dwarfs in intermediate polars can have spin periods which are much smaller than their orbital periods. Also these systems are believed to contain relatively undisturbed outer parts of an accretion disc. An interesting property of some intermediate polars is that they show optical

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brightness variations at a third period, which is equal to the beat period between the orbital and white-dwarf rotation periods. These brightness variations are the result of the reprocessing of X-rays in material which is corotating with the binary system (Patterson & Price 1981). For a review of the properties of intermediate polars we refer to a recent paper by Warner (1983).

In this paper we present the results of optical photometry of the intermediate polar AO Psc/H2252−035 (Griffiths *et al.* 1980). This source has been observed extensively in the X-ray, UV and optical parts of the spectrum (White & Marshall 1981; Patterson & Price 1981; Hassall *et al.* 1981; Pietsch *et al.* 1984; Van der Woerd, de Kool & van Paradijs 1984; see these papers for further references). The optical light curve of AO Psc contains three periodic components: an orbital brightness variation at a period of 3.5 hr and two pulsations, one at the white-dwarf spin period of 805 s and another at a beat period of 859 s.

We derive new epochs of maximum light for these three light curves. Combining these with previously published values we obtain a first significant measurement of the spin-up rate of the white dwarf in AO Psc. The observed spin-up rate is in good agreement with the value predicted by Lamb & Patterson (1983) for accreting magnetized white dwarfs rotating near their equilibrium period.

2 Observations

We observed AO Psc during five nights in 1983 and six nights in 1984 (see Table 1), using the Walraven five-colour photometer on the 90 cm Dutch telescope at ESO, La Silla (Lub & Pel 1977). The procedures followed in the observations and in the reduction of the data are the same as in our earlier observations of this source, and have been described previously by Van der Woerd *et al.* (1984). Part of the 1983 observations were made simultaneously with *EXOSAT*. A preliminary description of these simultaneous X-ray/optical observations has been given by Pietsch *et al.* (1984).

Table 1. Observations.

Date		UT	JD	orbital phase
1983	Aug. 13	0633– 0915	5559.773– 5559.885	0.14–0.89
	Aug. 31	0331– 0705	5577.647– 5577.795	0.60–1.59
	Sep. 08	0440– 0617	5585.694– 5585.762	0.38–0.84
	Sep. 15	0210– 0805	5592.590– 5592.837	0.47–2.12
	Sep. 17	0440– 0700	5594.694– 5594.792	0.53–1.19
1984	Aug. 07	0425– 0859	5919.689– 5919.879	0.89–2.16
	Aug. 14	0642– 0742	5926.785– 5926.826	0.31–0.59
	Aug. 21	0332– 0803	5933.654– 5933.839	0.22–1.46
	Aug. 24	0351– 0605	5936.665– 5936.768	0.34–0.98
	Sep. 07	0136– 0407	5950.573– 5950.678	0.29–0.99
	Sep. 08	0128– 0322	5951.567– 5951.646	0.94–1.47

3 Results

In order to derive new times of maximum for the three light curves we have folded the data (separately for the five passbands and for the 1983 and 1984 data), using the previously obtained values of the periods (Van der Woerd *et al.* 1984). Since at a given orbital phase the two pulsations have a fixed phase difference, we have corrected each data point for the average contribution of the other pulsation, (obtained from a first iteration folding), to avoid a distortion of the folded light curve due to non-uniform sampling in orbital phase. It happens that the times of maximum light are only slightly affected by possibly non-uniform sampling along the orbit.

This mutual correction is of particular importance for the 805-s pulsation, because of its low amplitude. Furthermore, since this pulsation consists of two components mutually phase-shifted by half a cycle, the times of maximum light due to this pulsation have to be viewed with some caution. One component is due to emission directly from the white-dwarf surface, the other from reprocessing of X-rays at the far side of the accretion disc (i.e. not corotating with the orbital motion). The composite character of the 805-s pulsation was suspected by Van der Woerd *et al.* (1984) on the basis of the wavelength dependence of its amplitude, and was confirmed by the observation of a 180° phase shift which occurred during one night in our 1983 observations (Pietsch *et al.* 1984). The data for this night were not used in the determination of the epoch of maximum light in 1983. No such phase shifts were observed in the 1984 data.

Table 2. Epochs of maximum light for H2252−035.

HJD	N	O−C	Reference
orbital variations			
3808.6820	−7054	−0.00328	White and Marshall (1981)
4428.8730	−2909	−0.00959	Patterson and Price (1981)
4530.6375	−2229	0.00964	Motch and Pakull (1981)
4815.0674	−328	0.00164	Van der Woerd (1984)
5246.5948	2556	0.00937	Kubiak (1983)
5559.6010	4648	−0.00078	this paper
5919.5935	7054	−0.00700	this paper
short pulsation			
3848.32685	−111121	−0.00204	White and Marshall (1981)
4530.63722	−37908	0.00101	Motch and Pakull (1981)
4815.00308	−7395	0.00149	Van der Woerd et al.(1984)
5263.00085	40676	0.00238	Van der Woerd et al.(1984)
5559.50606	72492	−0.00108	this paper
5919.50769	111121	−0.00176	this paper
long pulsation			
4428.85176	−74994	−0.00097	Patterson and Price (1981)
4530.64273	−64752	−0.00010	Motch and Pakull (1981)
4815.00358	−36140	0.00046	Van der Woerd et al.(1984)
5246.60275	7287	0.00049	Kubiak (1983)
5263.00124	8937	0.00045	Van der Woerd et al.(1984)
5492.90900	32070	0.00095	Williams et al.(1984)
5592.50199	42091	0.00025	this paper
5666.58320	49545	−0.00010	Williams et al.(1984)
5919.50671	74994	−0.00142	this paper

The times of maximum light (averaged over the five passbands), for the 1983 and 1984 data separately, are given in Table 2, together with their cycle numbers. For convenience we also list the values determined previously. Two of the latter values, reported by Van der Woerd *et al.* (1984) have been changed. One contains a misprint (the orbital epoch HJD 4530.6750 should read HJD 4530.6375). The other change is due to a more refined analysis of the data obtained in 1982 October; the above described interaction was inadvertently omitted previously, to avoid the mutual distortion of the 805-s and 859-s pulsations (859-s epoch HJD 5263.00000 changes into 5263.00124).

From the results of linear least-squares fits of the times of maximum light to cycle number N ($HJD_{max}=HJD_O+NP$) we find that the differences between the observed (O) times of maximum light of both pulsations and the calculated values (C) show a clear trend with time. This trend can be well represented by a quadratic relation between (O−C) and cycle number, which indicates that the pulsation periods change, with $\dot{P}$ given by the quadratic coefficient $b=\frac{1}{2}P\dot{P}$. We have therefore made a quadratic least-squares fit $HJD_{max}=HJD_O+NP_O+\frac{1}{2}P_O\dot{P}N^2$. An F-test shows that this quadratic fit is better than a linear one at 87 and 98 per cent confidence levels for the 805-s and 859-s pulsations, respectively. The orbital period does not change significantly (see Fig. 3).

The results of the least-square fits are given in Table 3. The constancy of the orbital period is consistent with the long time-scale for orbital decay expected from evolutionary calculations of mass-exchanging low-mass binaries (see e.g. Joss, Rappaport & Verbunt 1983). We therefore expect that the changes of the two pulsation frequencies are equal. This is confirmed by our observations; from Table 3 we find $\dot{\nu}_{805}=\dot{P}_{805}/P^2_{805}=1.01\pm0.26\times10^{-16}\,s^{-2}$, and $\dot{\nu}_{859}=0.89\pm0.15\times10^{-16}\,s^{-2}$.

The frequency difference between the two pulsations corresponds to a beat period of 12927.88±0.13 s, which is equal to the orbital period to within one part in 50000. At orbital maximum light the two pulsations have a phase difference of 0.49±0.02. These results confirm to a high degree of accuracy the relations between the three periods first found by Patterson & Price (1981) and Motch & Pakull (1981).

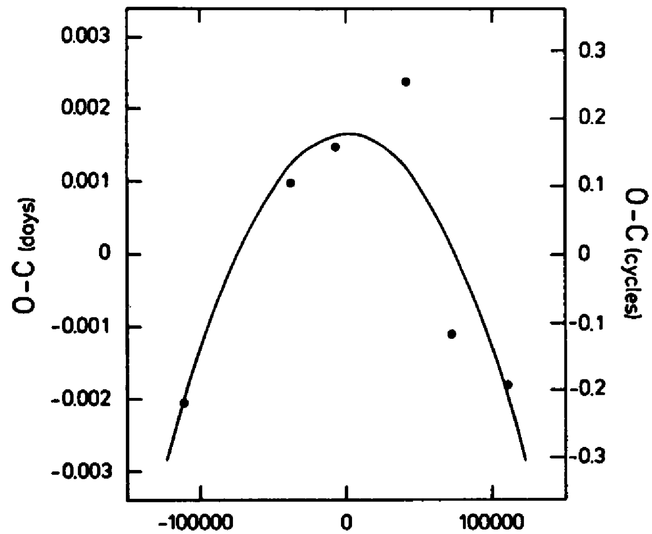

Figure 1. O−C values for the times of maximum light of the 805-s pulsation of AO Psc/H2252−035, for an assumed constant value of the pulse period. The parabolic fit through the data corresponds to a period derivative $\dot{P}=-6.54\times10^{-11}$.

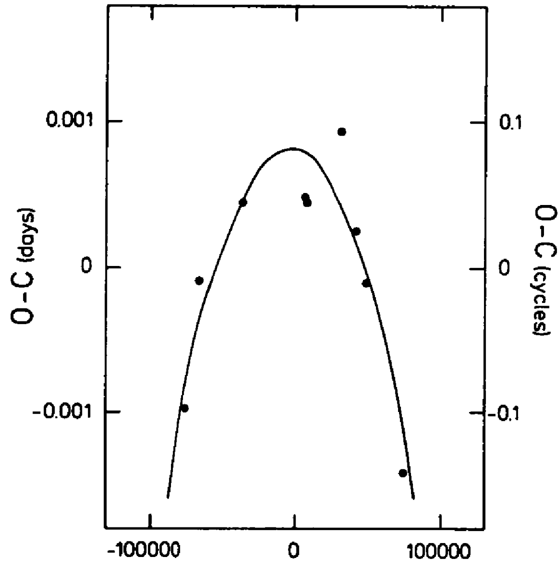

Figure 2. Same as Fig. 1, for the 859-s pulsation, with $\dot{P} = -6.59 \times 10^{-11}$.

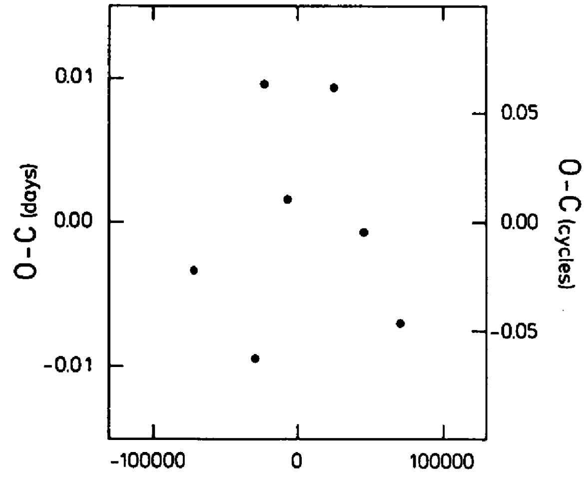

Figure 3. O−C values for the times of maximum of the orbital light curve. There is no evidence for a change of the orbital period.

4 Discussion

Our results increase the number of intermediate polars, for which a spin-up rate of the white dwarf is known, to three. The other two sources are DQ Her and EX Hya, which have been observed over long time intervals, before the intermediate polars were recognized as a distinct class of objects.

Lamb & Patterson (1983) proposed that the theory of Ghosh & Lamb (1979a, b), which describes the accretion torques on accreting magnetized neutron stars, is applicable to the intermediate polars. They assumed furthermore that the white-dwarf spin periods are not far

Table 3. Periods and period derivatives for AO Psc.

	orbit[1]	short pulse[2]	long pulse[2]
HJD_0	4864.14289 ±0.00294	4883.92085 ±0.00060	5174.18125 ±0.00017
P_0(s)	12927.64 ±0.06	805.2034 ±0.0005	858.6860 ±0.0002
$\dot{P}$ (10^{-11} s s^{-1})	...	−6.54 ±1.72	−6.59 ±1.09

[1] linear fit
[2] quadratic fit

from their equilibrium value. With plausible values for the accretion rate (corresponding to a luminosity of 2×10^{34} erg s^{-1}) they predicted for H2252−035 a white-dwarf spin-up rate of 5×10^{-11}.

As for DQ Her and EX Hya, the agreement between the observed and predicted spin-up rates for H2252−035 is very good, and our present results give some support to the suggestion of Lamb & Patterson (1983) that the rotation periods of white dwarfs in intermediate polars are not far from their equilibrium values.

The magnetic fields of white dwarfs in intermediate polars (B_0~10^6 G) inferred from the observed spin period (assumed to be approximately equal to the equilibrium period) are an order of magnitude below those for AM Her-type systems. However, King *et al.* (1985) argued that this result is difficult to reconcile with current ideas on the evolution of cataclysmic variables. They pointed out that the observed difference in the orbital period distribution for these two types of magnetic variables strongly suggest that intermediate polars evolve into AM Her-type systems, through loss of orbital angular momentum due to magnetic braking and gravitational radiation (*cf.* Chanmugam & Ray 1984), and conclude that the white dwarfs in these two groups do not have systematically different magnetic fields.

If the argument of King *et al.* (1985) is correct, there would be no *a priori* reason why the observed changes of white-dwarf rotation periods could not deviate widely from the values predicted by Lamb & Patterson (1983). In order to clarify whether the success of these predictions is a chance coincidence, or not, an extension of the sample of intermediate polars with measured values of the white-dwarf spin-up rate is clearly desirable.

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