# On the orbital period of the magnetic cataclysmic variable HU Aquarii

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**Abstract.** We present an analysis of ULTRACAM light curves of the magnetic cataclysmic variable HU Aquarii which were taken at the VLT in May 2005. Since the light curves were serendipitously obtained during a low state, they allowed us to determine the binary and the stellar parameters with high accuracy. The light curve was decomposed into the components originating from the accretion spot, the photosphere surrounding it and the white dwarf itself, which allowed us to extract the eclipse light curve for the pure white dwarf. Combined with high-time resolution observations with different instruments over a 12 year baseline it was possible to get exact eclipse timings of the white dwarf and thus establish a significant deviation from a linear ephemeris. If described by a quadratic term, the period decreases by $-1.13 \times 10^{-11}$ ss$^{-1}$. Interpreting this change in period as a pure angular momentum loss (AML) effect, the rate of $\dot{J} = -4.9 \times 10^{35}$ erg is much too high to be explained by gravitational radiation alone.

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## INTRODUCTION

Magnetic cataclysmic variables are close binaries consisting of a magnetic white dwarf and a late-type main-sequence star in synchronous rotation The late-type star loses matter via Roche-lobe overflow. The matter follows firstly a ballistic trajectory and is then captured by the magnetic field of the white dwarf. The plasma being accreted cools via bremstrahlung and cyclotron radiation [1]. In eclipsing systems where the white dwarf and the accretion stream are obscured by the late type star at the inferior conjunction, every component – accretion spot, accretion stream and white dwarf – is eclipsed for different orbital phase intervals and leaves its sign in eclipse ingress and egress. In bright accretion states the largest and most obvious features during ingress and egress come from the accretion spot and the accretion stream. Both are time-variable in brightness and locus and thus not constant in the orbital phase they occur. To determine the system parameters with high accuracy and especially to determine long term changes in the orbital period a fixed marker is needed. This is obviously the eclipse of the white dwarf. Unfortunately most of the times the white dwarf is outshone by the much brighter accretion stream. Merely when the white dwarf comes out of eclipse it can be seen undisturbed. Since this is a short term event ($\sim$ 15 seconds) high time resolution data are of utmost importance.

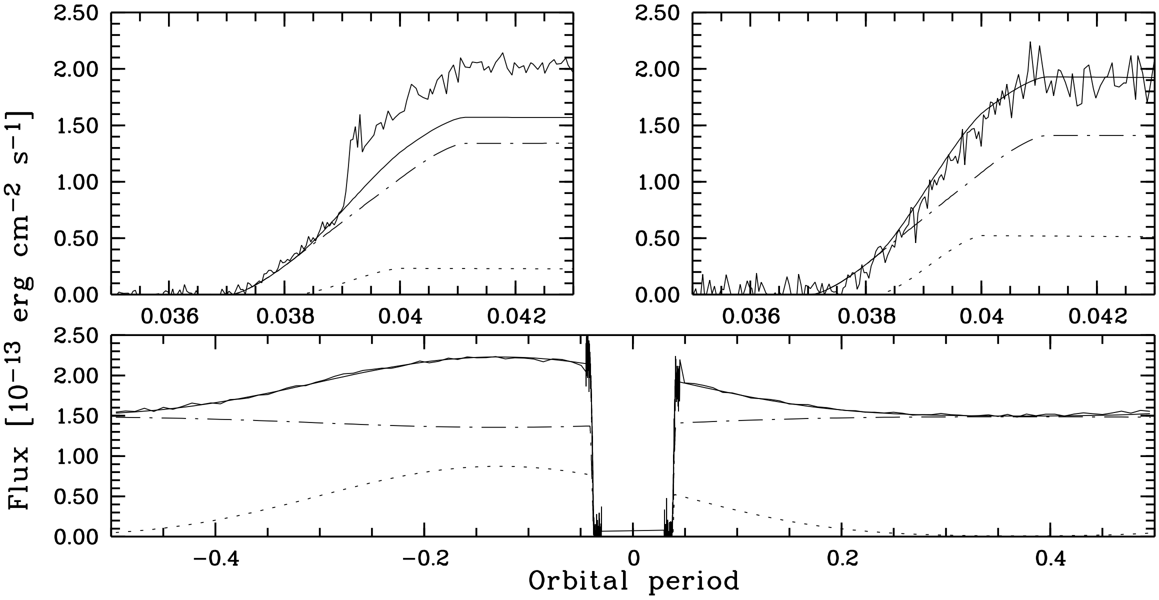

**FIGURE 1.** The plot shows the ULTRACAM data obtained in May 13 - 16, 2005 for a complete orbit (bottom) in *u* and for the eclipse egress in *u* (upper right) and *r* (upper left). Overplotted is the white dwarf model resulting from a fit to the *u* band data. The solid line shows the summed contribution from the white dwarf (dashed line) and the spot (dotted line). The plot in the upper left illustrates the additional cyclotron component. The ULTRACAM light curve was composed of all ULTRACAM eclipses from 2005 and the light curve from May, 13 for out of eclipse times.

## DETERMINING THE SYSTEM PARAMETERS

We obtained high-speed photometry with ULTRACAM mounted to the VLT in May 13 - 16, 2005 with a time resolution of 0.5 seconds, when the system was in a low accretion state. For the 5 eclipses in u,g,r we determined the times of white dwarf and spot ingress and egress. With the measured eclipse width, the measured white dwarf width, the orbital period and an assumed a M-R relation for the white dwarf, it is straight forward to compute the system parameters as a function of *i*, which we take from the literature [2]. The temperature of the white dwarf was determined from the spectral energy distribution using ULTRACAM data and HST-FOS spectra, which were exempted from the contribution of the accretion stream. The resulting system parameters are summarized in Table 1.

## DETERMINING THE EPHEMERIS

With the known system parameters we computed a light curve of the naked white dwarf. This in turn was used as a template to determine the times of the white dwarf eclipse in light curves obtained between 1993 and 2005. Since the ingress of the white dwarf dwarf was outshone by the accretion stream in all light curves aside from the ULTRACAM

**TABLE 1.** Measured timings from the ULTRACAM run in 2005 and the resulting system parameters for an inclination of $i = 85.5$.

| | |
|---|---|
| Eclipse width | 586.3(3) sec |
| White dwarf width | 30.6(3) sec |
| Mass ratio q | 0.241(1) $M_\odot$ |
| Mass of WD | 0.879(5) $M_\odot$ |
| Mass of secondary | 0.212(1) |
| Azimuth spot | 46(1)° |
| Colatitude spot | 23(2)° |
| $T_{WD}$ | 13500(200) K |
| $T_{Spot}$ | 25500(1500) K |
| $A_{Spot}/A_{WD}$ | 0.05(2) |
| d | 183(3) pc |

**TABLE 2.** Short overview of the used data for measuring the white dwarf eclipse times.

| Date | Instrument | Filter | Time resolution | No. of eclipses |
|---|---|---|---|---|
| 1993 | MCCP | V | 0.5 s | 8 |
| 1996 | HST | | 2.5 s | 4 |
| 1999,2000,2001,2002 | OPTIMA | white | 1.0 s | 7 |
| 2002,2005 | ULTRACAM | u | 0.5 s | 7 |

run in 2005, we used the white dwarf egress to adjust our template. The used data are summarized in Table 2.

A linear regression to the data showed residuals up to 20 seconds, after including a quadratic term the $\chi^2$ of the fit decreased significantly, but the fit is still not satisfying (see Fig. 2). The residuals imply a variable change in period on a times scale of years. Using the quadratic fit as a the simplest approach the ephemeris is

$$BJED = 2449216.394063(11) + E \times 0.0868204324(13) - E^2 \times 4.83(26) \times 10^{-13} \quad (1)$$

which gives a decrease in period of $\dot{P} = -1.13 \times 10^{-11}$ ss$^{-1}$. Over the time of the used data this amounts to $\Delta P = 4.2 \times 10^{-3}$ s and implies a time scale of $\frac{P}{\dot{P}} = 2.14 \times 10^7$ yr for the spin down of the period. Interpreting this period decrease as a pure AML effect, the implied rate is $\dot{J} = -4.9 \times 10^{35}$ erg.

## DISCUSSION

A change in period is observed in several CVs ([3]) and the reason for the period decrease is still a matter of subject. If interpreted as a period decrease due to genuine AML, it can help to test the predicted AML rates in the evolution of CVs. According to the standard theory HU Aqr as a system below the period gap should lose angular momentum due to gravitational radiation emission. With the system parameters from Table 1 one gets an AML rate of $\dot{J}_{GR} = -1.0 \times 10^{34}$ erg, which is clearly below the loss rate resulting from the observed period decrease. A period decrease of pure

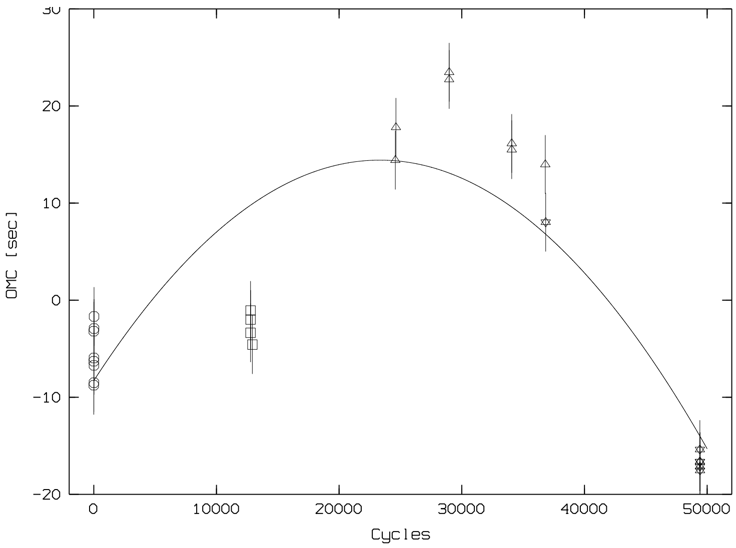

**FIGURE 2.** O-C plot after substraction of the linear fit (Symbols: MCCP – hexagon, HST-FOS – square, Optima – triangle, Ultracam – star)

gravitational radiation origin would be a factor of 50 less than observed. Thus, there must be an additional braking mechanism. It is still under discussion if the magnetic braking breaks down, when the star becomes fully convective, as supposed by the standard model. The reduced magnetic braking model [4] suggests that there is no cut-off of the magnetic braking when the secondary becomes fully convective and that the AML rate predicted by the standard model is to high. The reduced magnetic braking results in an angular momentum loss rate of $\dot{J} = -1.43 \times 10^{33}$ erg, which is two orders of magnitude below the required one and thus is not able to explain the period decrease of HU Aqr. Ignoring the cut-off of magnetic braking the predicted loss rate for the standard model [5] can explain the loss rate implied by the observed period decrease, but this induces severe problems since neither period gap nor period minimum are compatible with that explanation. Alternative explanations for a period change due to the magnetic activity of the secondary [6] or an unseen third body will be explored in a forthcoming paper. Since these explanations suggest a periodic change of the orbital period, further monitoring of HU Aquarii is essential.

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