Light Curve Morphology Study of UW CrB – Evidence for a 5 d Superorbital Period

Pasi Hakala1*, Linnea Hjalmarsdotter,2 Diana C. Hannikainen2,3 Panu Muhli2†

1 Tuorla Observatory, Väisäläntie 20, University Of Turku, FIN-21500 Piikkiö, Finland.
2 Observatory, P.O. BOX 14, University of Helsinki, FIN-00014 University of Helsinki, Finland.
3 Metsähovi Radio Observatory/TKK, Metsäholmantie 114, FIN-02540 Kylmäjärvi, Finland.

ABSTRACT
Since its discovery in 1990, UW CrB (also known as MS1603+2600) has remained a peculiar source without firm classification. Our current understanding is that it is an Accretion Disc Corona (ADC) low mass X-ray binary. In this paper we present results from our photometric campaign dedicated to studying the changing morphology of the optical light curves. We find that the optical light curves show remarkable evidence for strongly evolving light curve shapes. In addition we find that these changes show a modulation at a period of ∼ 5 days. We interpret these changes as either due to strong periodic accretion disc warping or other geometrical changes due to disc precession at a period of 5 days. Finally, we have detected 11 new optical bursts, the phase distribution of which supports the idea of a vertically extended asymmetric accretion disc.

Key words: Accretion discs – X-ray binaries.

1 INTRODUCTION
UW CrB (also known as MS1603+2600) was discovered in X-rays during the Einstein medium sensitivity survey (Morris et al. 1990). Morris et al. (1990) also identified the optical counterpart of the X-ray source. A star with blue, accretion disc-like spectrum with Balmer emission lines was found close to the X-ray position. Subsequent optical photometry revealed a period of 111 minutes. Morris et al. (1990) also noted that the shape of the optical light curve seemed to change from one night to the other. The system is located at a high galactic latitude of 47°. This, together with its low X-ray flux of 1.14×10⁻¹² erg/s (Morris et al. 1990), suggests that either the source is underluminous in X-rays for a low mass X-ray binary (LMXB) or that it is actually located in the galactic halo.

Earlier models for UW CrB have involved both LMXB and magnetic CV scenarios (Morris et al. 1990, Ergma & Vilhu 1993). Based on evolutionary calculations Ergma & Vilhu prefer the LMXB option. Hakala et al. (1998) compared the ROSAT spectra of UW CrB with soft X-ray spectra of various classes of interacting binaries. Their conclusion was that the only class where the spectral fits seemed to match those of the source was that of the soft X-ray transients (SXT) in quiescence. This could also explain the relatively low $F_X/F_{opt}$ ratio the system has. The main complication for this explanation arises from the fact that, according to our knowledge, the optical light curves of other SXT’s do not vary like they do in UW CrB. The same is true for the magnetic CV hypothesis (AM Herculis type). Hakala et al. (1998) report a negative result from their search for circular polarisation.

Hakala et al. (1998) also published the results of further optical photometry together with the ROSAT observations. They confirmed the extreme variability seen in the optical light curve pulse shapes. Even if there are dramatic changes in the optical light curve shape, the overall optical flux level does NOT seem to vary much. The analysis of ROSAT data proved that the soft X-ray spectrum of UW CrB can be modelled with a single blackbody component with a temperature of 0.24 keV. The ROSAT data also showed that there is no significant interstellar absorption in the direction of the source.

Mukai et al. (2001) presented ASCA observations of UW CrB. They detect a single type I X-ray burst, which rules out a black hole as the primary component in the system (which was suggested by Hakala et al. 1998). These bursts have also been seen in the optical (Muhli et al. 2004, Hynes et al. 2004.). Mukai et al. (2001) propose that UW CrB is a short period X-ray dipper, like 4U1916-05. They also note that the system would probably in this case have to reside in the outer galactic halo, and could have formed in the globular cluster Palomar 14, which is located 11° from UW CrB at a distance of 73.8 kpc. The Chandra obser-
observations of UW CrB by Jonker et al. (2003) modelled the X-ray spectrum with a simple powerlaw of spectral index α = 2.0. They conclude that the source is an accretion disc corona (ADC) system at a distance of 11–24 kpc. Finally, two XMM-Newton observations, separated by 2.5 days, have shown that in addition to the changes in the shape of the optical light curve, also the X-ray and UV light curves change significantly on a time scale of days (Hakala et al. 2005). They also detect several X-ray bursts confirming the neutron star nature of the primary. The overall XMM-Newton EPIC X-ray spectrum cannot be fitted with a simple model. In addition to the blackbody component and the powerlaw used to model the ROSAT and Chandra spectra Hakala et al. (2005) find that an additional thermal plasma (MEKAL) component is required in order to fit the spectrum. The phase resolved X-ray spectra suggest that the most likely cause for the X-ray modulation is changing partial covering of the X-ray emission components over the orbital cycle. This strongly suggests that UW CrB is an ADC source with a thick or warped asymmetric accretion disc.

In this paper we will present further (high time resolution) photometry of UW CrB. We will discuss the observations, followed by a statistical analysis of our data. We will also analyse the 11 optical bursts detected in our data set, together with the bursts detected earlier in various data sets (Hynes et al. 2004, Hakala et al. 2005). Finally we discuss the possible origin of the modulation detected and its implication on our understanding of UW CrB, and accretion discs in LMXB’s in general.

2 OBSERVATIONS

We observed UW CrB on the Nordic Optical Telescope (NOT), La Palma, on four different occasions. The system setup was identical during these runs. NOT was used with a Cassegrain spectrograph/imager ALFOSC, which in turn was equipped with a Loral-Lesser, thinned, AR coated, back illuminated 2048 by 2048 CCD detector. This detector has a relatively flat quantum efficiency of more than 80% all the way from B to I band. In order to increase the time resolution, the chip was subwindowed and binned by a factor of 2. Multiples of these spikes are seen due to the very sparse illumination 2048 by 2048 CCD detector. This detector has a relatively flat quantum efficiency of more than 80% all the way from B to I band. In order to increase the time resolution, the chip was subwindowed and binned by a factor of 2. As a result we were able to obtain time series photometry at a true time resolution of 13 s (10 s exposure time and 3 s readout overhead). All the observations were done in white light in order to maximize the S/N. All the data were reduced in a normal manner for CCD images (i.e. bias subtraction and flat field correction). The field typically included at least two other stars. On all occasions we used the “bright”, about 14th mag star, located ∼ 30” NNE of of UW CrB (star “C”, see Hakala et al. 1998 for a finding chart) as a comparison star.

Our first data set was obtained in February 1999, and covers data from four consecutive nights. The second data set, obtained in May 1999, consists of six consecutive half nights of data. The source was observed for about two orbital cycles each half night, enabling the construction of a phase folded light curve each night. The light curves from May 1999 (folded into 100 phase bins) are plotted in Figure 1. Each subplot contains data from a single night. Our third data set (from June/July 2002) consists of eight consecutive half-nights of observations. As mentioned above, the instrument setup was identical and also the same comparison star was used. These data are plotted in Figure 2. We typically have about 1000 photometric points per night, which means that each of the phase bins in the folded plots (Figures 1 & 2) is an average of ten measurements (i.e. about 100 s effective exposure time).

### Table 1. Observing log. All data were obtained in white light with a typical time resolution of 10-15 s.

| Start time (HJD) | Data set | Duration (d) |
|-----------------|----------|--------------|
| 2451212.705     | Feb 1999 | 0.083        |
| 2451213.727     | Feb 1999 | 0.077        |
| 2451214.669     | Feb 1999 | 0.125        |
| 2451215.676     | Feb 1999 | 0.124        |
| 2451304.561     | May 1999 | 0.178        |
| 2451305.562     | May 1999 | 0.176        |
| 2451306.572     | May 1999 | 0.162        |
| 2451307.569     | May 1999 | 0.162        |
| 2451308.559     | May 1999 | 0.162        |
| 2451309.577     | May 1999 | 0.154        |
| 2452455.386     | Jul 2002 | 0.172        |
| 2452456.378     | Jul 2002 | 0.176        |
| 2452457.452     | Jul 2002 | 0.105        |
| 2452458.377     | Jul 2002 | 0.157        |
| 2452459.378     | Jul 2002 | 0.077        |
| 2452460.376     | Jul 2002 | 0.175        |
| 2452461.379     | Jul 2002 | 0.171        |
| 2452462.383     | Jul 2002 | 0.169        |
| 2452492.379     | Aug 2002 | 0.086        |

3 DATA ANALYSIS

#### 3.1 Period Analysis

Given the nature of the pulse profiles in UW CrB, it is far from clear that traditional astronomical period analysis methods such as power spectral analysis or epoch folding search perform correctly. All these methods rely on the fact that the signal to be found is both stable in period and in pulse shape. As this is not entirely the case here, the resulting periodograms must be viewed with caution.

We have chosen to tackle our data using various techniques in order to remove any method-dependent bias from our results. This is also sensible, since the changing light curve pulse shapes present a challenge to any period analysis method. We have started the “usual” way, i.e. ignoring the changes in the light curve shape, we have computed the Lomb-Scargle power spectral density periodogram (Scargle 1982). This is shown in Figure 3. The top panel shows the power vs. log(period) over a wide range of periods, and the lower panel zooms in near the 111 minute period. The only periods present here seem to be the 0.07710315 d modulation, its second harmonic (due to the secondary minimum in some light curves) and another spike at roughly 0.0783 d. Multiples of these spikes are seen due to the very sparse sampling of the data in time (i.e. the window function).

Next, we proceeded with an epoch folding search, where the data are phase binned and then a null hypothesis of the
source being constant over the trial period is tested using a $\chi^2$ test (i.e. if the data do not vary over a given trial period a low value of $\chi^2$ is obtained, since the data are well represented by just a constant value over the trial period). This method is more sensitive to non-sinusoidal pulses, since increasing the number of phase bins will allow for sharper features to be detected. In our analysis we have used 30 phase bins.

Figure 4 (top) shows the resulting periodogram (period vs. $\chi^2$) from our epoch folding search algorithm. Now the method correctly picks up the right spike (0.07710315 d) as the highest one. Again, there is severe aliasing in the periodogram due to the 1 day gaps in the data and (not properly seen in Figure 4) due to the shortness of the period and the very long 3.5 year gap between the two data sets.

In order to further investigate the effects of the sampling on our periodogram we have performed a simulation. First, we have modelled the average light curve of UW CrB by fitting a 6th order Fourier series to the data. Having done this, we were able to create a synthetic light curve with exactly the same sampling (time points) and similar period and pulse shape to our real data. This was done by adding a similar amount of noise to the fit as there was in the original light curve. We then proceed to perform exactly the same
epoch folding search on the synthetic data that we did on the real data. The resulting synthetic periodogram is plotted under the real one in Figure 4. This plot is a true reproduction of the effects of the sampling (window function) and binning used in the epoch folding search on the data that has a period and average pulse shape like those of UW CrB. We can see that most of the features are reproduced, except for the spikes marked by short vertical lines in the upper panel of Figure 4. We investigated these spikes further, and they turned out to be offset from the spikes corresponding to the 0.07710315 d period (and its window-related aliases) by a constant frequency of $\sim 0.2$ cycles/d, i.e. they correspond to...
to a period of \( \sim 0.0783 \text{ d} \). We will return to this period later in this paper, but it is interesting to note that this would be the synodic (beat) period if the system would have another longer period of 5 days. This could be a disc precession period and would then imply prograde precession. In other words the 0.0783 d period would be a positive superhump period.

3.2 Light curve shapes

We have observed UW CrB on 19 different nights altogether. During all of these nights we detect a clear modulation at the 111 minute period. However, there is striking night-to-night variability in the pulse shape of the light curve. This is not entirely random though, since the light curve minimum seems to be relatively stable in phase. Another striking feature in the light curves is that the light curve pulse shape seems to repeat roughly at a period of 5 days. We first noted this in the 1999 data (Figure 1), where there is unfortunately only one pair of light curves that are 5 days apart. This prompted us to obtain a second, longer observation (2002 data, Figure 2) that now contains 3 pairs of light curves separated by 5 days. Simply by visual inspection one can see that the first night’s very broad asymmetric eclipse is roughly reproduced during the sixth night, also the second and third nights’ light curves resemble those of the seventh and eighth nights’. Next we proceed to examine this apparent similarity in more detail.

We have performed some statistical tests in order to quantify the visually apparent 5 day periodicity in the modulation of the light curve shapes. To start with, we have correlated the folded light curves in pairs against each other. The largest possible correlation coefficient was searched for using cross-correlation with about 0.05 maximum phase shift between the pairs of light curves (allowing for some error in period). As a result, quite high values for the correlation coefficient were generally obtained (see Table 2 for the actual coefficients). This is a natural consequence of the fact that all light curves do show a minimum, even if it is sometimes shallower and broader. Studying correlation alone, there is no evidence for the 5 day cycle in the first data set (correlation between nights 1 and 6 is 0.895). However, the correlations between the pairs of nights 5 days apart in the second data set are amongst the highest in the whole table (0.927, 0.984 and 0.957). It is very difficult to assess the significance of these correlation values though. If we simply assume that our 91 correlation values are a representative sample of correlation coefficients for any light curve pairs, we can sort the correlation coefficients and study the locations of the 4 pairs of nights that are 5 day apart from each other. From this it follows that the correlation coefficients that we are interested in have ranks 1, 4, 17 and 32 among the 91 coef-
Hakala, Hjalmarsdotter, Hannikainen & Muhli

Figure 4. Epoch folding search periodogram around the best period. The top plot shows the periodogram of the data with the beat period aliases marked with vertical tick marks. The lower plot is a periodogram from simulated data having a similar average (but constant!) pulse shape as the real data, i.e. it is a representation of a simulated window function. Note that the peaks marked by the vertical lines in top plot are missing. See main text for discussion.

| Nights | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  | 11  | 12  | 13  | 14  |
|--------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| 1      | 1.0 |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 2      | 0.939 | 1.0 |     |     |     |     |     |     |     |     |     |     |     |     |
| 3      | 0.817 | 0.825 | 1.0 |     |     |     |     |     |     |     |     |     |     |     |
| 4      | 0.795 | 0.836 | 0.642 | 1.0 |     |     |     |     |     |     |     |     |     |     |
| 5      | 0.923 | 0.909 | 0.759 | 0.875 | 1.0 |     |     |     |     |     |     |     |     |     |
| 6      | 0.895 | 0.905 | 0.722 | 0.716 | 0.893 | 1.0 |     |     |     |     |     |     |     |     |
| 7      | 0.742 | 0.795 | 0.788 | 0.911 | 0.776 | 0.610 | 1.0 |     |     |     |     |     |     |     |
| 8      | 0.904 | 0.910 | 0.769 | 0.946 | 0.940 | 0.857 | 0.928 | 1.0 |     |     |     |     |     |     |
| 9      | 0.925 | 0.923 | 0.757 | 0.773 | 0.932 | 0.959 | 0.679 | 0.905 | 1.0 |     |     |     |     |     |
| 10     | 0.910 | 0.874 | 0.629 | 0.637 | 0.868 | 0.937 | 0.487 | 0.803 | 0.933 | 1.0 |     |     |     |     |
| 11     | 0.899 | 0.833 | 0.606 | 0.526 | 0.765 | 0.869 | 0.412 | 0.733 | 0.876 | 0.931 | 1.0 |     |     |     |
| 12     | 0.656 | 0.730 | 0.772 | 0.842 | 0.719 | 0.563 | 0.927 | 0.848 | 0.650 | 0.462 | 0.387 | 1.0 |     |     |
| 13     | 0.893 | 0.909 | 0.793 | 0.940 | 0.933 | 0.838 | 0.911 | 0.984 | 0.874 | 0.751 | 0.657 | 0.875 | 1.0 |     |
| 14     | 0.926 | 0.942 | 0.779 | 0.885 | 0.942 | 0.928 | 0.808 | 0.958 | 0.957 | 0.885 | 0.849 | 0.740 | 0.941 | 1.0 |

Table 2. The correlation coefficients between all the possible pairs of nights. Night 1–6 correspond to the 'May 1999', whilst nights 7–14 are the 'July 2002' nights.

Now we can get a very conservative upper limit for the probability of this happening at random, i.e. the probability that 4 randomly selected coefficients (out of 91) would all be within the 32 highest. This upper limit is 1.3% . In addition, we can define another test statistic by summing up the ranks of 4 randomly chosen correlation coefficients and comparing their distribution (approximately Gaussian, except for the wings) with the value (54) we get for our four pairs of nights separated by 5 days. As a result, we find that in only 0.47% of cases the 4 randomly drawn pairs of nights have a summed correlation rank lower than 54. In conclusion, the distribution of correlation coefficient values, together with the values obtained for the 4 pairs of nights that are 5 days apart, support the idea that the light curve shape is modulated at approximately 5 d period.

Our second line of attack for measuring the significance of the 5 d cycle is based on cluster analysis of light curve shapes. Here we have employed a method based on unsupervised neural networks called Self Organizing Maps (SOM) Kohonen (1988) (See also Hakala et al. (2002) for a detailed description of the algorithm and recent usage of SOM in regularization). SOM is a topology-conserving clustering algorithm that is capable of finding (learning) intrinsic clustering in N-dimensional data. In our case we have used a 1-
For the clustering purposes we can think of a single 100 bin phase-folded light curve as a point in 100-dimensional space. This means that (using July 2002 data only) our 8 folded and phase-binned light curves define 8 input data points for our SOM algorithm. Considering cluster analysis for 8 data points may seem unreasonable to start with, but given some constraints we show that it does make sense.

The idea is that if we define a maximum number of say 5 cluster centres, then, as we observe 5 light curve shapes over the 5 d period, each cluster would represent the shape of the light curve at a different phase over that 5 d period. Now if we take our second data set that covers 8 nights, this means that in principle the first 5 nights’ data could be mapped into different clusters, but the algorithm has to decide where to place the light curves of the remaining 3 nights. Now, IF there would be a 5 day cycle in the modulation light curve shape, the clustering algorithm should place the sixth light curve in the same cluster as the first, the seventh light curve in the same cluster as the second and the eighth light curve in the same cluster that contains the third night’s data. If there is no modulation, then the algorithm should spread the last three night’s data evenly in the five clusters. Thus, as SOM is an iterative stochastic algorithm and if we run this several times with different seeds for the random number generator, we can examine at what level the SOM algorithm finds evidence for the 5 d period (i.e., how often the data separated by 5 nights gets classified into the same cluster). Based on 100000 cluster analysis runs on our data we find that in 99.994% of the cases the algorithm comes out with a final clustering that places all three pairs of light curves observed five days apart in the same clusters. In order to further quantify this result we performed some simulations on non-correlated data. These showed that the chance probability of such clustering is 21.6%.

Finally, the “synodic peaks” in Figure 4 that show a constant separation from the the main periodic peak (and its aliases) imply a synodic period of 0.0783 d, which in turn, given the orbital period of 0.07710315 d, further implies a superorbital period of 5.04 d. Based on these three different pieces of evidence we conclude that the light curve shape is modulated at this period. The simplest explanation for such modulation is either accretion disc precession or other periodic changes in the geometry of the disc. We can identify the superhump period as 0.0783 d, whilst the 0.077103 d period is the orbital period. These, together with the correlation analysis, suggest a precession period of ~ 5 d for the accretion disc. This enables us to estimate the system mass ratio using the empirical formula for the superhump period excess (Patterson, 2001): q = 0.216e, where e = Psh/Porb/Psh.

In our case e = 0.016 implies a mass ratio q = 0.072. Finally, as type I X-ray bursts have been detected from the source, we assume that the compact object is a neutron star. As such its most likely mass is 1.4M⊙. This then implies M2 ~ 0.1M⊙ for the secondary, a factor of two less than expected for a Roche lobe filling main sequence secondary at the given period. We thus conclude that the secondary is likely to be somewhat evolved.

Figure 5. The individual burst light curves with model fits. The fit parameters are listed in Table 2.

4 OPTICAL BURSTS

As already noted earlier by Muhli et al. (2004) and Hynes et al. (2004), UW CrB shows clear optical bursts that are most probably associated with the type I X-ray bursts seen earlier (Mukai et al. 2001). They can be modelled by an instantaneous rise followed by an exponential decay (Hynes et al. 2004). These bursts are also well represented in our data set, where we can isolate 11 clear bursts. These are listed in Table 2. Typically the bursts have a peak amplitude equal to the out-of-burst flux and an e-folding time of 10–25 s. The total flux emitted during a burst corresponds roughly to the flux emitted by the rest of the system during 1–2 e-folding times (in optical). The mean errors for the amplitude (height), e-folding time and the fluence are (based on model fitting), 0.26, 0.1 s and 3.8 respectively.

We observed a total of eleven bursts in our data set (Figure 5.). This means approximately one burst per 5.9h or 3.2 binary orbits. This is compatible with the estimate of one burst in 6.3h presented by Hynes et al. (2004) earlier (based on only five bursts).

The observed bursts have e-folding times in the range
of 10–25 s and their maximum amplitudes are not corre-
related with the e-folding times. We have also looked at the
orbital phases of the bursts. In order to increase our sta-
tistics we have, in addition to our 11 bursts reported here,
added another five bursts reported by Hynes et al. (2004)
and yet another five seen during the XMM-Newton obser-
vations (Hakala et al. 2005), bringing the total number of
bursts to 21. The burst distribution as a function of orbital
phase is plotted in Figure 6. Interestingly the bursts are
concentrated on the first half of the orbit and 16 out of the 21
detected bursts occurred in the orbital phase range 0.0–0.5.
This is in agreement with the view that the accretion disc
is thicker (or more warped) on the side where the accretion
stream impacts the disc, i.e. the disc prevents us from see-
ing at least some of the bursts that occur at late orbital
phases. Since our sample is only 21 events, we have carried
out simulations in order to investigate the significance of
the asymmetry in the burst phase distribution. As a result we
conclude that if the burst phase occurs at random, then we
would see 16 or more bursts at phase range 0.0–0.5 only in
1.3% of cases. However, if we allow the 16 or more bursts
happen in any phase range of length 0.5, then the chance
probability increases to 20.8%. More burst detections are
clearly needed, but based on the distribution we have, it is
possible that the disc is asymmetric and that the true burst
frequency is higher than reported here.

It is interesting to note that all of the bursts modelled in
this paper (Fig. 5. and Table 3.) seem to be rather similar in
flux irrespective of their orbital phase. This is curious, since
if we believe that the optical bursts are a result of reproces-
sing of X-ray bursts in a warped/vertically extended asym-
metric disc and/or the secondary, we would expect that the
bursts seen during the 0.5–1.0 phase range should be fainter,
as there is i) more obscuring matter, i.e. the disc bulge, ob-
scuring the view of the inner disc and ii) less projected area
in the plane of sky available for reprocessing (assuming there
is less vertical extension on the other edge of the disc). How-
ever, there is no clear evidence for any fainter bursts in our
data. One possible explanation could be that maybe the op-
tical bursts are produced by the enhanced optical emission
due to the reprocessing in the inner disc. In this case it would
be obvious that sometimes we simply don’t see the repro-
cessing area at all and that this could happen more often
in the 0.5–1.0 phase range, where the disc is generally more
elevated. Yet the changing disc structure would occasionally
enable us to see some bursts at any orbital phase. The key
test would be simultaneous high time resolution X-ray and
optical observations of the bursts in order to measure the
possible reprocessing lags. However, since UW CrB is most
likely an ADC source (and faint both in X-rays and optical),
where we believe that the NS is not seen directly, observing
such lags might be almost impossible.

5 CONCLUSIONS
It is rather obvious from our photometry, that UW CrB is
most likely a high inclination system, where at least a par-
tial eclipse of an accretion disc is always visible, and that
the bulk of the optical orbital modulation is caused by ei-
ther varying self-shadowing and projected area of a non-
axisymmetric accretion disc and/or a partial eclipse of a
such disc by the secondary star. Hakala et al. (2005) noted
that the X-ray light curves can be best modelled by varying
partial covering of the X-ray emitting region over the orbital
period. This suggests that the accretion disc either has sub-
stantial asymmetric vertical structure or it is clearly warped
out of the orbital plane. Our current data cannot distinguish
between these models. Our interpretation of the optical light
curves does not make any assumptions on the nature of the
compact object itself. It is still worth noting that precession
of accretion discs is a well known phenomenon in high mass
ratio systems (Whitehurst, 1988). Given the magnitude of
effects seen in UW CrB, it is possible that this system is
an extreme example of the superhump phenomenon seen in
nonmagnetic cataclysmic variables with similar orbital pe-
riods, i.e. SU UMa systems (Patterson, 2001).

ACKNOWLEDGMENTS
Just days before submission, an article by Mason et al.
(2008) appeared on-line reporting results similar to ours.
Our analysis independently confirms their findings on the
5d cycle related to the morphology changes in the accre-
tion disc. We would like to thank Prof. Phil Charles and
Dr. Osmi Vilhu for very useful comments and discussions.
We would also like to thank the Nordic Optical Telescope staff for enabling the flexible scheduling required to cover the time baselines required. The data presented here have been taken using ALFOSC, which is owned by the Instituto de Astrofisica de Andalucia (IAA) and operated at the Nordic Optical Telescope under agreement between IAA and the NBIAFG of the Astronomical Observatory of Copenhagen. The authors gratefully acknowledge support from the Academy of Finland. PH and DCH have been supported by the Academy of Finland research fellowships. Finally, we would like to thank the anonymous referee for very constructive criticism that helped to improve the paper considerably.

REFERENCES
Ergma E. and Vilhu O., 1993, A&A, 277, 483
Hakala P.J., Chaytor D., Vilhu O., Piirola V., Morris S.L., Muhli P., A&A, 1998, 333, 540.
Hakala P.J., Muhli P., Dubus G., 1999, MNRAS, 306, 701.
Hakala P., Ramsay G., Muhli P., Charles P., Hannikainen D.C., Mukai K., Vilhu O., 2005, MNRAS, 356, 1133.
Hynes R.I., Robinson E.L., Jeffery E., 2004, ApJ, 608, 101.
Jonker P.G., van der Klis M., Kouveliotou C., Mendez M., Lewin W.H.G., Belloni T., 2003, MNRAS, 346, 684.
Mason P.A., Robinson E.L., Gray C.L., Hynes, R.I., 2008, ApJ, 685, 428.
Morris S.L., Liebert J., Stocke J.T., Gioia I.M., Schild R.E. and Wolter A., 1990, ApJ, 365, 686.
Muhli P., Hakala P.J., Hjalmarsdoter L., Hannikainen D.C., Schultz J., 2004, RMxAC, 20, 211.
Mukai K., Smale A.P., Stahle C.K., Schlegel E.M., Wijnands R., 2001, ApJ, 561, 938.
Patterson J., 2001, PASP, 113, 736.
Scargle J.D., 1982, ApJ, 263, 835.
Whitehurst R., 1988, MNRAS, 232, 35.