Detection of negative superhumps in a LMXRB – an end to the long debate on the nature of V1405 Aql (X1916-053)

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Abstract.
Two similar periodicities (3001 and 3028 s) are known from the X-ray and optical light curves of V1405 Aql, a low mass X-ray Binary (LMXRB). Two competing models have been offered for this system. According to the first, V1405 Aql is a triple system. The second model invokes the presence of an accretion disc that precesses in the apsidal plane, suggesting that the shorter period is the orbital period while the longer is a positive superhump. Re-examination of previously published X-ray data on V1405 Aql reveals an additional periodicity of 2979 s. The periods in V1405 Aql fit well within a newly found relation where the ratio between the negative superhump deficit (over the orbital period) and the positive superhump excess is a function of orbital period in cataclysmic variables that show both types of superhumps. Therefore, the 2979-s period is naturally interpreted as a negative superhump. The recently found 4.8-d period in the X-ray light curve of V1405 Aql is consequently understood as the precession of the accretion disc in the nodal direction. This is the first firm detection of negative superhumps and nodal precession in a LMXRB. Our results thus confirm the classification of V1405 Aql as a permanent superhump system. The 13-year argument on the nature of this intriguing object has thus finally come to an end.

1. Introduction
Permanent superhump systems show superhumps (quasi-periodicities shifted by a few percent from their orbital periods) in their optical light curves. The phenomenon is observed during their normal brightness state, unlike in SU UMa
systems. Permanent superhumps can either be a few percent longer than the orbital periods and are then called ‘positive superhumps’, or shorter than the orbital periods – ‘negative superhumps’. The positive superhump is explained as the beat between the binary motion and the precession of an accretion disc in the apsidal plane. Similarly, the negative superhump is understood as the beat between the orbital period and the nodal precession of the disc (Patterson 1999).

Permanent superhumps have been observed in about 20 cataclysmic variables. Superhumps have been seen in a few LMXRBs in outburst (e.g. O’Donoghue & Charles 1996), however, there have not been any confirmed detection of permanent superhumps in a LMXRB.

White & Swank (1982) and Walter et al. (1982) independently found 3001-s periodic dips in the X-ray light curve of the LMXRB V1405 Aql. Schmidtke (1988) and Grindlay et al. (1988) reported a detection of an optical periodicity at 3028 s. The difference between the X-ray and optical periods was confirmed by further extensive observations of V1405 Aql.

Two basic models have been offered so far for the periodicities found in V1405 Aql. According to the first model (Grindlay et al. 1988), the longer 3028-s period is the binary inner orbital period, while the shorter 3001-s period is the beat period between the binary period and the ∼4-d orbital period of a third companion. The second model (White 1989) suggests that the 3001-s period is the binary period and that the 3028-s period is a positive superhump. The debate on the nature on V1405 Aql has still been continued (Chou, Grindlay, & Bloser 2001; Homer et al. 2001; Haswell et al. 2001). Here we argue that the second model is correct, and present evidence for a third period that we identify as the negative superhump. For more details see Retter, Chou & Bedding (2001).

2. Observations and Analysis

We have re-analysed existing RXTE data that were presented by Chou et al. (2001). In Fig. 1a the power spectrum of 10 successive runs in 1996 May is presented. In addition to the two known periods (3001 and 3028 s, marked as f₁ and f₂) and their 1-d aliases, there is a third peak (f₃) together with its 1-d alias pattern. After fitting and subtracting the two known frequencies, the third, which corresponds to the periodicity 2979.3±1.1 s, becomes the strongest peak in the residual power spectrum (Fig. 1b). To test the possibility that a combination of the window function and the two known periods is responsible for the third periodicity, we planted sinusoids of the two known periods in the data (plus noise). The result (Fig. 1c) did not show any other significant peak in the power spectrum. We also rejected manually the points corresponding to the dips from the light curve. The new period was still present in the corresponding power spectrum (Fig. 1d). Finally, we divided the data into two parts (first and last five runs), and the new periodicity appeared in both.

3. Discussion

The 2979-s period is shorter than the 3001-s period by about 0.7%. Assuming that the 3001-s period is the orbital period and that the 3028-s period is a posi-
Figure 1. Power spectra of 10 successive runs in 1996 May: 
(a) Raw data; In addition to the two previously known periods – the 3001-s period (marked as \( f_1 \)) and the 3028-s period (\( f_2 \)), there is a third structure of peaks centered around 2979 s (\( f_3 \)); ‘a\(_i\)’ (\( i=1-3 \)) represent 1-d aliases of ‘f\(_i\)’. 
(b) After fitting and subtracting \( f_1 \) and \( f_2 \), \( f_3 \) is still present and becomes the strongest peak in the power spectrum.
(c) Power spectrum of a synthetic light curve, consisting of sinusoids of the two previously known periods (plus noise) sampled as the data thus illustrating the window function. This shows that aliases of the known periods cannot explain the \( f_3 \) peak.
(d) Same as (a) after rejecting the dips. The peak at \( f_3 \) dominates the power spectrum. This test confirms that this frequency is not a consequence of random variations in the structure of the dips.

tive superhump, the new period is naturally explained as a negative superhump. Patterson (1999) proposed that the negative superhump deficit is about half the positive superhump excess. The corresponding ratio in V1405 Aql (0.8) is somewhat larger than this. In Fig. 2 we show this ratio for all systems known to have both positive and negative superhumps, and we see a clear trend as a function of orbital period. Our result for V1405 Aql fits this trend very well.

Our suggestion that the 2979-s period is a negative superhump implies a nodal precession of \( \sim 4.8 \) d. Indeed Chou et al. (2001) found that the phase jitter of the X-ray dips in the 1996 May data is modulated with a period of 4.86 d. Homer et al. (2001) reached a similar conclusion from a different dataset and found a period of \( 4.74 \pm 0.05 \) d. Therefore, the superhump model can explain this periodicity as well. The classification of V1405 Aql as a permanent superhump system is thus firmly established, and our result puts an end to the 13-year debate on the nature of this intriguing system.

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Figure 2. The relation between the orbital period and the ratio between the negative superhump deficit and the positive superhump excess in systems that have both types of superhumps. The periods in V1405 Aql obey this relation.

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