Superhumps in V1141 Aquilae

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Abstract

The results of the CCD observations of the 2002 superoutburst of V1141 Aql are described. We have detected clear superhumps characterized by the period of 0.05930(5) days. There was another, much weaker, modulation in the light curve of V1141 Aql. Its amplitude is equal to 0.012 ± 0.002 mag and its period to 0.03923(8) days. We have also discovered quasi periodic oscillations (QPOs) with a mean period equal to 130 s and amplitude of 0.025 ± 0.004 mag.

Key words: Stars: individual: V1141 Aql – binaries: close – novae, cataclysmic variables

1 Introduction

V1141 Aql was suspected for variability by Kukarkin et al. (1951) and confirmed as a variable star by Kukarkin et al. (1968). It was later classified as a dwarf nova by Vogt and Bateson (1982). In subsequent documentation, V1141 Aql is only referred to as a dwarf nova (Bruch et al. 1992, Downes et al. 1997).

We learnt about the continuing outburst of V1141 Aql from the VSNET e-mail 1 reporting the observation of Maciej Reszelski and indicating that the star reached a magnitude of 15.2 at 2002 July 8.927 UT. Previous brightenings of V1141 Aql were reported on 2001 July and 2000 September (Reszelski 2002, private communication).

2 Observations

Observations of V1141 Aql reported in the present paper were obtained over five nights during the period from 2002 July 9 to 14 at the Ostrowik station of the Warsaw University Observatory.

The 60-cm Cassegrain telescope equipped with a Tektronics TK512CB back illuminated CCD camera was used. The scale of the camera was 0.76″/pixel providing a 6.5′ × 6.5′ field of view. The full description of the telescope and camera was given by Udalski and Pych (1992).

1[vsnet-outburst-4198] http://vsnet.kusastro.kyoto-u.ac.jp/vsnet.Mail/vsnet-outburst/msg04198.html
We monitored the star in “white light”. This was due to the lack of an autoguiding system, not yet implemented after recent telescope renovation. Thus we did not use any filter because we wanted to have the shortest possible exposure times and avoid elongation of the star shapes.

The exposure times were from 60 to 150 seconds depending on the atmospheric conditions, seeing and the brightness of the object.

A full journal of our CCD observations of V1141 Aql is given in Table 1. In total, we monitored the star during 13.71 hours and obtained 436 exposures.

| Date       | Time of start | Length of run [hr] | Number of frames |
|------------|---------------|--------------------|-----------------|
| 2002 Jul 09/10 | 465.4379      | 2.38               | 83              |
| 2002 Jul 10/11 | 466.4358      | 2.41               | 83              |
| 2002 Jul 12/13 | 468.4532      | 2.34               | 84              |
| 2002 Jul 13/14 | 469.4181      | 3.09               | 91              |
| 2002 Jul 14/15 | 470.3911      | 3.49               | 95              |
| Total       | –             | 13.71              | 436             |

### 2.1 Data Reduction

All the data reductions were performed using a standard procedure based on the IRAF package.

The profile photometry has been derived using the DAOphotII package (Stetson 1987).

Relative unfiltered magnitudes of V1141 Aql were determined as the difference between the magnitude of the variable and the magnitude corresponding to the sum of intensities of four comparison stars. These comparison stars are marked in the chart displayed in Fig. 1. The accuracy of our measurements varied between 0.008 and 0.072 mag depending on the atmospheric conditions and brightness of the variable. The median value of the photometry errors was 0.015 mag.

### 2.2 Light curves

Fig. 2 presents a general photometric behavior of V1141 Aql as observed in July 2002. The brightness of the star is at the same level during the first two nights indicating that the variable was caught at the beginning of its superoutburst. During the subsequent nights one can see a systematic decrease of the brightness with a rate of 0.15 mag per day.

Fig. 3 presents the individual light curves of the star for our five nights. In all observations the short-term modulation (i.e. superhumps) is clearly visible, confirming that V1141 Aql is a member of the SU UMa group of dwarf novae.

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2IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under a cooperative agreement with the National Science Foundation.
Figure 1: Finding chart for V1141 Aql covering a region of 6.5 \times 6.5 \text{ arcminutes}. The variable is marked by an open circle. The positions of the comparison stars are also shown.

Figure 2: The general photometric behavior of V1141 Aql during its 2002 superoutburst
Figure 3: The light curves of V1141 Aql observed during five nights in July 2002
3 Period of the Superhumps

3.1 Power spectrum

From the light curves we removed the long term decrease and then analyzed them using ANOVA statistics (Schwarzenberg-Czerny 1996). The resulting periodogram is shown in Fig. 4. The most prominent peak is detected at a frequency of $f = 16.878 \pm 0.020$ c/d, which corresponds to the period $P_{sh} = 0.05928(7)$ days ($85.36 \pm 0.10$ min). The first harmonic of this frequency is also marginally visible around 32-34 c/d.

![Figure 4: ANOVA power spectrum of the light curve of V1141 Aql.](image)

The light curve from each night was separately fitted with the sum of six harmonics characterized by a period of 0.05928 days. In the next step, we have prewhitened our light curves removing the variability with $P_{sh}$. The ANOVA power spectrum of the resulting light curve is shown in Fig. 5. One can clearly see a distinct peak at $f_2 = 25.49 \pm 0.05$ c/d, which corresponds to a period of $P_2 = 0.03923(8)$ days ($56.5 \pm 0.1$ min). The inset shows the prewhitened light curve of V1141 Aql phased over this period. The amplitude of this modulation is equal to $0.012 \pm 0.002$ mag.

![Figure 5: ANOVA power spectrum of the light curve of V1141 Aql prewhitened with $P_{sh}$. Inset shows the light curve phased with a period of 0.03923 days corresponding to the highest peak.](image)
To verify the accuracy of this period we performed a separate frequency analysis of each night. The clear peaks at a frequency of approximately 25.5 c/d were present in all resulting periodograms indicating that the new period is most probably a real feature.

However one can clearly see that in the periodogram shown in Fig. 5 the peak with frequency 26.49 c/d has almost the same power as peak near 25.5 c/d. Thus we can not exclude that the frequency 26.49 c/d is the real one and the true period of 0.01 mag modulations is equal to 0.03775 days.

### 3.2 O – C Diagrams

One of the most popular methods for determining the period of the light modulation and its time derivative is the formulation of the O – C diagram for the times of extrema. In our case the maxima were clearer than the minima and thus we decided to use them in our analysis.

Table 2: Times of maxima observed in the light curve of V1141 Aql during its 2002 superoutburst

| $E$ | $HJD_{max}$       | O – C [cycles] |
|-----|-------------------|----------------|
| 0   | 2452465.4960      | 0.0337         |
| 16  | 2452466.4410      | −0.0357        |
| 17  | 2452466.5020      | −0.0074        |
| 51  | 2452468.5165      | −0.0475        |
| 67  | 2452469.4670      | −0.0243        |
| 68  | 2452469.5330      | 0.0883         |
| 83  | 2452470.4150      | −0.0432        |
| 84  | 2452470.4780      | 0.0189         |

In total, we determined eight maxima peaks listed in Table 2 together with their cycle numbers $E$. The least squares linear fit to the data from Table 2 gives the following ephemeris:

$$HJD_{max} = 2452465.494(3) + 0.05932(6) \cdot E$$

indicating that the value of the superhump period $P_{sh}$ is equal to 0.05932(6) days (85.42 ± 0.09 min). This is in excellent agreement with the value obtained in the previous paragraph from the power spectrum analysis.

Table 2 also shows O – C data computed using our times of maxima and ephemeris (1). They are also shown in Fig. 6. Larger O – C values observed at the beginning and the end of our observation period may suggest that the period of the superhumps is increasing. With a data span interval of only six days the assertion that there has been a change in the period is only hypothetical. However the formal fit of the second order polynomial results in the following relation:

$$HJD_{max} = 2452465.495(3) + 0.05925(15) \cdot E + 1.0(1.7) \times 10^{-6}E^2$$

indicating that the period was likely increasing with a rate of $\dot{P} \approx 3 \times 10^{-5}$. 

This is not typical behavior among SU UMa stars where we often observe decreasing periods of superhumps.

Finally, by combining our two determinations of $P_{sh}$, we derive its value as $0.05930(5)$ days, which corresponds to $85.39 \pm 0.07$ min.

![Figure 6: O – C diagram for 8 times of superhump maxima of V1141 Aql.](image)

### 4 Quasi Periodic Oscillations

Quasi periodic oscillations (QPOs) are low amplitude and short period luminosity modulations observed in the light curves of cataclysmic variables. They were first discussed by Patterson et al. (1977). The periods of these modulations are in the range of $\sim 50$-1000 s and their amplitudes are usually only a few times of 0.01 mag. However occasionally larger amplitudes are observed. For example, in 1974 QPOs in VW Hyi had an amplitude reaching 0.12 mag (Warner & Brickhill 1978). The most prominent modulations with an amplitude of 0.2 mag were observed by Kato et al. (1992) during the 1992 superoutburst of SW UMa. During two other superoutbursts of this star in 1986 and 1996 QPOs were also detected but with significantly smaller amplitudes (Robinson et al. 1987, Nogami et al. 1998).

We decided to search for QPOs in the light curve of V1141 Aql. For this purpose we prewhitened our light curve using two periods described in section 3.1. The variations with $P_{sh}$ and its six harmonics were subtracted from the light curve of the star for each night separately. From the resulting light curve we removed sinusoid characterized by the period 0.03923 days and an amplitude of 0.012 mag. For such a prewhitened light curve we computed the ANOVA power spectrum for frequencies in the range of 0 - 900 c/d. This is shown in Fig. 7.

There is a clear group of distinct peaks around frequency 670 c/d in Fig. 7. The subharmonic of this frequency at 335 c/d is also visible. The highest peak in this power spectrum has a frequency of 663.8 c/d which corresponds to the period of 130 s. The question is whether this frequency is real in
view of the fact that the typical exposure time used in our observations was 90 s, i.e. almost 70% of the detected period.

The mean amplitude of these 130 s QPOs in V1141 Aql is equal to $0.0103 \pm 0.0015$ mag. Due to the fact that during our observations we averaged the brightness of the stars over 70% of the period, the true amplitude of the suspected QPOs is higher. This can be easily computed from the following expression connecting the real amplitude $A_r$ with observed amplitude $A_o$, the period of the QPOs $P_{QPO}$ and exposure time $T_{exp}$:

$$A_r = A_o \frac{\pi T_{exp}}{P_{QPO}} \sin^{-1} \left( \frac{\pi T_{exp}}{P_{QPO}} \right)$$

Thus finally the real amplitude of the QPOs in V1141 Aql is $0.025 \pm 0.004$ mag.

Figure 7: ANOVA power spectrum of the prewhitened light curve of V1141 Aql showing the clear group of peaks around frequency 670 c/d

Figure 8: ANOVA power spectrum of the simulated light curve of V1141 Aql
To verify the reality of the QPOs in the light curve of V1141 Aql we performed a simple test. After prewhitenning the raw light curve of the star with all three detected periods there is no any periodic signal left. The observed noise is characterized by the Gaussian function with $\sigma$ equal to 0.024 mag. Thus we constructed an artificial light curve using a sinusoid with an amplitude of 0.025 mag and a period of 130 s. For each of our observations we computed the mean brightness of this artificial curve averaging it over $\pm 45$ s around the time of observation. Then the noise described by the Gaussian function with $\sigma = 0.024$ mag was added. For such a constructed light curve we computed the ANOVA power spectrum, which is shown in Fig. 8. Both power spectra shown in Figs. 7 and 8 are similar, suggesting that 130 s QPOs in the light curve of V1141 Aql are real phenomena. Of course, there is more noise in the power spectrum of the real light curve and it may be caused by a high order of linear combinations of frequencies described in section 3.1 which were not removed during prewhitenning. The source of the additional noise is certainly related to the quasi-periodic behavior of the detected oscillations. In our simulated light curve we inducted only the sinusoidal variations with the constant value of the period.

Finally, we conclude that the light curve of 2002 superoutbursts of V1141 Aql contained QPOs with a mean period of 130 s and an amplitude of $0.025 \pm 0.004$ mag.

5 Discussion

We have presented the results of the observations of the 2002 brightening of V1141 Aql. Detection of the clear superhumps during this event directly proves that V1141 Aql belongs to the group of SU UMa variables.

The value of the superhump period was equal to 0.05930(5) days which corresponds to $85.39 \pm 0.07$ min. Our data seem to indicate that the superhump period was increasing at a rate of $\dot{P} \approx 3 \times 10^{-5}$. It seems to agree with the pattern observed in other SU UMa systems, where long-period systems show a decrease of the superhump periods, and short-period systems or infrequently outbursting SU UMa variables tend to show an increase of the superhump period (see Kato et al. 2001a for discussion).

Previous brightenings of V1141 Aql were observed in July 2001 and September 2000 (Reszel- ski 2002, private communication). The star then reached a magnitude of approximately 15.5. This may indicate that these brightenings were also superoutbursts and the supercycle in V1141 Aql lasts slightly less than one year.

The interesting thing is lack of ordinary outbursts which may be real phenomenon suggesting a resemblance of V1141 Aql to the group of "tremendous outburst amplitude dwarf novae" or "TOADs" (Howell et al. 1995). On the other hand, the lack of the ordinary outburst may be an observational effect as well. V1141 Aql, even in the superoutburst, is faint. Ordinary outbursts being 1-2 mag fainter than superoutbursts could be below the limiting magnitude reached by astronomy amateurs.

Other properties of V1141 Aql are also similar to those shown by TOADs. The star seems to be a twin of SW UMa - a well known member of TOADs. SW UMa was intensively studied during its 1996 superoutburst. According to Semeniuk et al. (1997) the superhump period of SW UMa is only slightly shorter that the period of V1141 Aql. Thus both stars have similar superhump periods, similar supercycle lengths and are characterized by the presence of interpulses (secondary humps) visible on the light curves in the second part of the superoutburst. Both stars also show clear QPOs in their superoutburst light curves and for both we do not observe ordinary outbursts. SW UMa was the
first variable of SU UMa type with an increasing period of superhumps (Semeniuk et al. 1997). Such behavior was observed only in the other short orbital period SU UMa stars such as V485 Cen (Olech 1997), AL Com (Nogami et al. 1997), V1028 Cyg (Baba et al. 2000) and HV Vir (Kato et al. 1998) and WX Cet (Kato et al. 2001b).

A comparison of the properties of V1141 Aql and SW UMa is shown in Table 3.

Table 3: Comparison of the properties of V1141 Aql and SW UMa

|                      | V1141 Aql | SW UMa |
|----------------------|-----------|--------|
| Supercycle           | 350 days  | 400 days |
| Amplitude of superoutburst | 5 mag.  | 7 mag.  |
| Superhump period     | 85.4 min. | 83.8 min. |
| Orbital period       | ?         | 81.8 min. |
| $P_{sh}$             | +3 $\times$ 10^{-5} | +8.9 $\times$ 10^{-5} |
| Interpulses          | yes       | yes    |
| QPOs                 | yes       | yes    |
| Ordinary outbursts   | no?       | no     |

Of course, we can not include V1141 Aql into the TOADs because according to Howell et al. (1995) the main property of this group is the amplitude of the superoutbursts higher than 6 mag. In the case of V1141 Aql this amplitude is around 5 mag, suggesting that this star may be a link between ordinary SU UMa stars and TOADs.

In addition to the clearly visible modulation connected with the superhumps we have also detected the weak signal characterized by an amplitude around 0.01 mag and a period of 0.03923(8) days ($56.5 \pm 0.1$ min). The nature of this periodicity is unknown. This cannot be the orbital period of the binary system because, according to the Schoembs & Stolz (1984) relation, it should be around 84 min. It could be a signature of the white dwarf rotation period, which in nonmagnetized systems such as SU UMa stars, is not synchronized with the orbital period.

We have also discovered quasi periodic oscillations (QPOs) with a mean period equal to 130 s and an amplitude of 0.025 $\pm$ 0.004 mag.

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