Curious Variables Experiment (CURVE).
CCD Photometry of V419 Lyr in its 2006 July Superoutburst.

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Abstract

We report extensive photometry of the dwarf nova V419 Lyr throughout its 2006 July superoutburst till quiescence. The superoutburst with amplitude of $\sim$ 3.5 magnitude lasted at least 15 days and was characterized by the presence of clear superhumps with a mean period of $P_{sh} = 0.089985(58)$ days (129.58 $\pm$ 0.08 min). According to the Stolz-Schoembs relation, this indicates that the orbital period of the binary should be around 0.086 days i.e. within the period gap.

During the superoutburst the superhump period was decreasing with the rate of $\dot{P}/P_{sh} = -24.8(2.2) \times 10^{-5}$, which is one of the highest values ever observed in SU UMa systems. At the end of the plateau phase, the superhump period stabilized at a value of 0.08983(8) days.

The superhump amplitude decreased from 0.3 mag at the beginning of the superoutburst to 0.1 mag at its end. In the case of V419 Lyr we have not observed clear secondary humps, which seems to be typical for long period systems.

Key words: Stars: individual: V419 Lyr – binaries: close – novae, cataclysmic variables

1 Introduction

Dwarf novae – a subclass of Cataclysmic Variable stars – are quite well studied interacting binary systems composed of late-type red dwarf secondary and white dwarf primary stars (Warner 1995, Hellier 2001). Matter transferred from the red dwarf forms an accretion disc around the white dwarf. Although in the last decade significant progress has been made in explaining the behaviour of dwarf novae light curves, some physical processes ongoing in these systems are still not fully understood (see for example Smak 2000, Schreiber and Lasota 2007). In particular, the thermal-tidal instability model of Osaki (1996, 2005) describing the phenomenon of
superoutbursts and superhumps may be tested by examination of SU UMa-type dwarf novae light curves. Additionally, objects near and inside the so called period gap are very important from an evolutionary point of view. Those systems give us an unprecedented opportunity to study the evolution of dwarf novae.

V419 Lyr is a poorly studied cataclysmic variable discovered by Kurochkin (1990) and originally classified as a Z Cam-type dwarf nova. Later, Nogami et al. (1998) caught this object in outburst and found superhumps in its light curve. Detection of superhumps together with characteristic properties of the outburst allowed them to classify V419 Lyr as a SU UMa-type dwarf nova, but short coverage of the eruption did not allow accurate determination of the superhump period. Nevertheless, there was a strong suggestion that V419 Lyr has one of the longest orbital periods known among SU UMa variables.

This object has been monitored at various photometric bands by the Variable Star Network (VSNET) (see for example Kato et al. 2004a). The observations from that program enabled a tentative determination of the supercycle period to be about $\sim 340$ days (Katysheva and Pavlenko 2003). Moreover, Morales-Rueda and Marsh (2002) obtained a spectrum of V419 Lyr during outburst showing a relatively broad absorption feature around 430-440 nm.

In this work we present an analysis of photometric data collected during the 2006 July superoutburst of V419 Lyr. The data are much richer than previous studies and provide us with an opportunity to determine parameters describing this system more precisely.

2 Observations and data reduction

The CURious Variable Experiment (CURVE) team (see for example Olech et al. 2004, 2006), alerted by the VSNET mailing list, found V419 Lyr in a very bright state on 2006 July 17/18. Subsequently the object was monitored on 13 consecutive nights (with a gap on July 24/25) until its return to quiescence on August 2/3. The observations were performed using a 0.6-m Cassegrain telescope equipped with a Tektronix TK512CB back-illuminated CCD camera. The image scale was 0\".76/pixel providing a 6\".5 $\times$ 6\".5 field of view (Udalski and Pych, 1992)

Observations were made unfiltered for two reasons. First, due to lack of an autoguiding system, we wished to keep exposures short in order to minimize guiding errors. Second, because our main goal was analysis of the temporal behaviour of the light curve, the use of filters might cause the object to be too faint to observe in quiescence. Exposure times were 90 seconds during the bright state and 100-150 seconds at minimum light.

All CURVE team data reductions were performed using a standard procedure based on IRAF\textsuperscript{1} package and the profile photometry has been derived using the DAOphotII package (Stetson 1987).

During preliminary analysis of the data we found the AAVSO archive containing several CCD observations of the same superoutburst of V419 Lyr made by observers from England (D.B.) and the United States (R.K.). Therefore we decided to combine our data to obtain better results.

D.B. used a 0.35-m Meade Schmidt-Cassegrain telescope with a Starlight Xpress SXV-H9 CCD camera. Data were taken unfiltered. Exposures were 40, 50 or 60 sec depending on conditions. The AIP4WIN package (Berry and Burnell 2000) was used to dark-subtract and flat-field all images before measuring them using aperture photometry. The magnitude of V419 Lyr was determined by differential photometry with respect to an ensemble of two nearby comparison stars.

R.K. used 0.25-m Meade LX-200 Schmidt-Cassegrain telescope equipped with an Apogee AP-47 CCD camera and clear filter characterized by IR block at 700 nm. MPO Canopus software (Warner 2007) was used for differential photometry of the variable with an average of four comparison stars.

Table 1 presents a journal of our CCD observations of V419 Lyr. In total, we observed the star for more than 48 hours on 14 nights and collected 3179 exposures.

\textsuperscript{1} IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
Table 1: Observational journal for the V419 Lyr campaign. O. Start and O. End correspond (for particular
nights) to times for first and last CCD frame made in Ostrowik observatory. D.B./R.K. Start and D.B./R.K End
correspond to data obtained by David Boyd and Robert Koff respectively. "Dur." Gives the total duration of
runs from all telescopes excluding the gaps.

| Date in 2006 | O. Start     | O. End     | D.B. Start  | D.B. End  | R.K. Start  | R.K. End  | Dur. [hr] | No. of points | < V > [mag] |
|-------------|--------------|------------|-------------|-----------|-------------|-----------|-----------|---------------|-------------|
| Jul 17/18   | 934.35741    | 934.48498  | -           | -         | -           | -         | 3.07      | 96            | 14.85       |
| Jul 18/19   | 935.34981    | 935.46236  | 935.4153    | 935.5366  | -           | -         | 4.48      | 430           | 14.87       |
| Jul 19/20   | 936.34761    | 936.45140  | -           | -         | -           | -         | 2.49      | 90            | 14.97       |
| Jul 20/21   | 937.34381    | 937.53570  | 937.4028    | 937.5556  | -           | -         | 5.08      | 524           | 15.07       |
| Jul 21/22   | 938.33272    | 938.35473  | 938.4610    | 938.5400  | 938.6425    | 938.9360  | 9.47      | 486           | 15.23       |
| Jul 22/23   | 939.34842    | 939.46027  | 939.4799    | 939.5819  | 939.6373    | 939.9487  | 12.06     | 717           | 15.31       |
| Jul 23/24   | 940.33218    | 940.46082  | 940.4018    | 940.5223  | -           | -         | 4.56      | 560           | 15.41       |
| Jul 24/25   | -            | -          | 941.4139    | 941.5463  | -           | -         | 3.18      | 426           | 15.54       |
| Jul 25/26   | 942.33893    | 942.46321  | -           | -         | -           | -         | 2.98      | 107           | 15.62       |
| Jul 26/27   | 943.33482    | 943.39914  | -           | -         | 943.6480    | 943.8573  | 6.57      | 239           | 15.84       |
| Jul 27/28   | 944.32455    | 944.44318  | -           | -         | 944.6359    | 944.9476  | 10.33     | 398           | 16.59       |
| Jul 28/29   | 945.33554    | 945.44203  | -           | -         | -           | -         | 2.56      | 67            | 17.36       |
| Jul 30/31   | 947.34226    | 947.43608  | -           | -         | -           | -         | 2.25      | 32            | 18.14       |
| Aug 2/3     | 950.32019    | 950.44469  | -           | -         | -           | -         | 2.99      | 87            | 17.63       |

3 Global light curve

Figure 1 presents the photometric behaviour of V419 Lyr in 2006 July and August. Dots and open circles
correspond to our CCD observations and visual estimates of AAVSO observers, respectively.

![Global light curve of 2006 superoutburst of V419 Lyr](image)

Figure 1: Global light curve of 2006 superoutburst of V419 Lyr. Dots and open circles denote our observations and AAVSO estimates, respectively. Solid line is a least squares linear fit to the plateau phase of the superoutburst.

The shape of the light curve corresponds to the standard picture of a superoutburst. First, the star rose rapidly from its quiescent level to a peak magnitude of around 14.5 mag. Due to the lack of observations, the
exact time of the rise is unknown. V419 Lyr was seen by AAVSO observers in a bright state on July 16. Two nights later, during our first run, the star was still at the same brightness and showing fully developed superhumps with a peak-to-peak amplitude of 0.3 mag - a feature characteristic of the beginning of a superoutburst. Thus we conclude that the July 2006 superoutburst started around July 15.

After reaching peak magnitude, V419 Lyr entered the plateau stage lasting about 11 days with an average decline rate of about 0.1 mag d$^{-1}$. The plateau stage ended rapidly on July 27 and during the next two days we observed the final decline stage with a change of brightness of about 1 mag d$^{-1}$. On July 30 the star was again in quiescence showing a mean brightness of 18.1 mag. Thus the entire superoutburst lasted about 15 days.

The linear fit to the plateau stage in Figure 1 is helpful in showing there was no rebrightening as has been
observed in some SU UMa systems (Kato et al. 2003a).

4 Superhumps

Figure 2 shows the light curves of V419 Lyr during thirteen individual nights. Filled circles correspond to the Ostrowik Observatory data, while open circles and squares represent D.B. and R.K. measurements respectively.

The magnitudes have been transformed to a common V system and detrended for purposes of Fourier power spectrum analysis. The superhumps are clearly visible and have an initial amplitude of 0.3 mag. Later the superhump amplitude gradually decreases and on August 2/3 is practically indistinguishable from noise.

4.1 ANOVA statistics

As we noted earlier, all light curves of V419 Lyr in superoutburst were detrended by removing a fit based on a first or second order polynomial. Then we analyzed them using ANOVA statistics (Schwarzenberg-Czerny 1996). The resulting periodogram is shown in Figure 3. It shows a very clear and dominant peak at frequency $f_0 = 11.107 \pm 0.010$ c/d, which we interpret as due to superhumps and corresponds to the period $P_{sh} = 0.09033(81)$ days.

![ANOVA power spectrum computed for data from nights July 17/18 - July 27/28.](image)

The spectrum has almost no 1-day aliases due to good coverage and the use of data from three sites - two from Europe and one from the United States. A small peak is also observed around 22 c/d, the first harmonic of the main frequency. We then prewhitened the light curve of V419 Lyr during the superoutburst with the main period and its first harmonic. The power spectrum of the resulting light curve shows no other periodicities.

4.2 The O-C analysis

To check the stability of the superhump period and to better determine its value, we constructed an $O - C$ diagram. Because the maxima in our case were almost always clearly visible and easier to measure than minima, we decided to use the timings of the former. Finally, we were able to determine 27 times of maxima which are listed in Table 2 together with associated errors, cycle numbers $E$, and $O - C$ values.
Table 2: Times of maxima observed in the light curve of V419 Lyr during its 2006 superoutburst

| Cycle | HJD-2 453 000 | Error  | O-C   |
|-------|---------------|--------|-------|
| 0     | 934.420       | 0.0015 | -0.1408|
| 11    | 935.425       | 0.0014 | 0.0281 |
| 12    | 935.517       | 0.0016 | 0.0505 |
| 22    | 936.420       | 0.0016 | 0.0859 |
| 33    | 937.408       | 0.0014 | 0.0660 |
| 34    | 937.497       | 0.0017 | 0.0551 |
| 45    | 938.408       | 0.0031 | 0.0907 |
| 47    | 938.669       | 0.0022 | 0.0800 |
| 48    | 938.757       | 0.0025 | 0.0580 |
| 55    | 939.383       | 0.0044 | 0.0149 |
| 57    | 939.562       | 0.0031 | 0.0042 |
| 58    | 939.650       | 0.0034 | -0.0177|
| 59    | 939.741       | 0.0029 | -0.0064|
| 60    | 939.831       | 0.0033 | -0.0062|
| 61    | 939.920       | 0.0033 | -0.0171|
| 66    | 940.369       | 0.0017 | -0.0272|
| 67    | 940.458       | 0.0025 | -0.0381|
| 78    | 941.443       | 0.0027 | -0.0914|
| 79    | 941.533       | 0.0030 | -0.0912|
| 88    | 942.444       | 0.0015 | -0.0782|
| 89    | 942.432       | 0.0033 | -0.1002|
| 103   | 943.696       | 0.0047 | -0.0530|
| 104   | 943.783       | 0.0044 | -0.0861|
| 111   | 944.407       | 0.0022 | -0.1513|
| 121   | 945.335       | 0.0056 | 0.1663 |
| 122   | 945.425       | 0.0056 | 0.1643 |
| 144   | 947.411       | 0.0051 | 0.2322 |

A least-squares linear fit to the data taken during the plateau phase of superoutburst gives the following ephemeris for the maxima:

$$HJD_{\text{max}} = 2453934.4326(41) + 0.089983(58) \cdot E$$

(1)

The above equation indicates that the mean superhump period was $P_{sh} = 0.089983(58)$ days, which agrees within errors with the determination based on ANOVA statistics. Combining these two measurements gives us our final estimate of the mean superhump period of V419 Lyr during its 2006 July superoutburst which is $P_{sh} = 0.089985(58)$ days (129.58 ± 0.08 min).

The $O - C$ values computed according to the ephemeris (1) are listed in Table 2 and also shown in Figure 4. It is clear that V419 Lyr, during its 2006 superoutburst, showed clear changes of superhump period. In the cycle range 0 – 70 the period was quickly decreasing. A second-order polynomial fit to E vs. HJD_{max} dependence in this range corresponds to the solid line in the bottom panel of Figure 4 and is expressed by the following ephemeris:

$$HJD_{\text{max}} = 2453934.42496(117) + 0.0908080(75) \cdot E - 1.125(97) \cdot 10^{-5} \cdot E^2$$

(2)

This equation indicates that the period derivative has the large value $\dot{P}/P_{sh} = -24.8(2.2) \times 10^{-5}$. This is
the second largest negative value detected in SU UMa stars. Figure 5, taken from Kato et al. (2003b) and Olech et al. (2003), shows the position of V419 Lyr on the $\dot{P}/P_{sh} \text{ vs } P_{sh}$ diagram. Only KK Tel had a faster period decrease during its 2002 June superoutburst (Kato et al. 2003b). It is interesting that both V419 Lyr and KK Tel are long superhump period dwarf novae with orbital periods very close or even within the period gap.

Figure 4: Upper panel: Evolution of the amplitude of superhumps observed in the 2006 July superoutburst of V419 Lyr. Lower panel: $O-C$ diagram for times of superhump maxima. Solid line corresponds to the quadratic ephemeris (2). Black and open squares denote normal and late superhump maxima respectively. Dashed line corresponds to the 5th order polynomial fit. Size of the squares is, on average, of the size of error bars.

It is worth commenting on the behaviour of the superhump period after cycle number $E = 70$. At that moment, the star was still in the plateau phase of the superoutburst, three days before entering the final decline, and superhumps were still clearly visible in the light curve. The $O-C$ values for cycle numbers from 70 to
111 can be roughly fitted with a straight line, which indicates that the period decrease had stopped and its value stabilized at \( P_{\text{sh}} = 0.08983(8) \) days.

The noisy maxima with cycle numbers above 120 are shifted by \( \sim 0.4 \) cycle with respect to the superhump maxima from earlier nights. This indicates that they may be connected with late superhumps or even with the orbital wave.

It is interesting that our \( O-C \) diagram could be also interpreted in different ways than "common superhump followed by transition to late superhump" scenario. Fitting a 5th order polynomial to the moments of maxima appears to work with the data about as well as a quadratic followed by a linear trend as described previously. We are not arguing in favor of this interpretation, simply saying that there might be other interpretations of the data.

### 4.3 Amplitude and shape

The upper panel of Figure 4 shows the evolution of the amplitude of superhumps through the entire superoutburst. In a typical SU UMa star, fully developed superhumps have an amplitude of about 0.3 mag and a characteristic tooth shape. Interestingly, these properties seem to be completely independent of the inclination of the orbit of the binary. As the outburst progresses, the amplitude gradually decreases and the profile of the humps changes. A few days after maximum, so-called secondary humps or interpulses become visible. In the beginning they are small but with time they may become as high as the main maxima - most probably evolving towards late superhumps.

V419 Lyr is an interesting case because it seems not to follow this scenario. On the nights of July 19/20 and 20/21 it clearly showed double maxima. However, these quickly disappeared. During subsequent nights there was hardly a trace of secondary humps. Very weak humps could be seen only on July 23/24 and 25/26 and quite strong ones on July 27/28.

We were curious about the reason for such behavior. The only property which strongly differs in V419 Lyr from typical SU UMa stars is its long superhump/orbital period placing it within the period gap. We therefore reviewed the literature to investigate the occurrence of secondary humps among long period systems (i.e. with superhump period \( > 0.08 \) days). The summary of our review is given in Table 3.

Among 21 reviewed stars only four show clear secondary humps. The rest of them show no interpulses at all or only a weak trace of them.

### 5 Conclusions

The orbital period of V419 Lyr is unknown. However, it is possible to estimate its value using the relation in Stolz and Schoembs (1984) connecting the period excess \( \varepsilon \) defined as \( P_{\text{sh}}/P_{\text{orb}} - 1 \) with the orbital period of the binary. This empirical relation is as follows:

\[
\varepsilon = 0.858(11) \cdot P_{\text{orb}} - 0.0282(2)
\]

Using the definition of \( \varepsilon \) and knowing \( P_{\text{sh}} \) for V419 Lyr, we were able to estimate the orbital period as \( P_{\text{orb}} \approx 0.086 \) days. This is slightly longer than two hours which indicates that V419 Lyr is a dwarf nova in the period gap.
Table 3: Occurrence of secondary humps in long period superhumpers

| Star      | $P_{sh}$ [days] | Clear | Poorly | Invisible | Ref       |
|-----------|-----------------|-------|--------|-----------|-----------|
| HS Vir    | 0.08077         | -     | +      | -         | 1,2       |
| V359 Cen  | 0.08092         | -     | +      | -         | 3,4       |
| V660 Her  | 0.081           | -     | -      | +         | 5         |
| V503 Cyg  | 0.08101         | +     | -      | -         | 6         |
| BR Lup    | 0.08220         | +     | -      | -         | 7,8       |
| V877 Ara  | 0.08411         | +     | -      | -         | 9         |
| AB Nor    | 0.08438         | -     | +      | -         | 10        |
| V369 Peg  | 0.08484         | -     | -      | +         | 11        |
| HV Aur    | 0.08559         | +     | -      | -         | 12        |
| EF Peg    | 0.08705         | -     | +      | -         | 13,14     |
| TY PsA    | 0.08765         | -     | +      | -         | 15,16     |
| BF Ara    | 0.08797         | -     | -      | +         | 17        |
| KK Tel    | 0.08803         | -     | -      | +         | 18        |
| DV UMa    | 0.08869         | -     | +      | +         | 19,20     |
| V419 Lyr  | 0.0901          | -     | +      | -         | this study,21 |
| UV Gem    | 0.0902          | -     | +      | -         | 22        |
| V344 Lyr  | 0.09145         | -     | -      | +         | 23        |
| YZ Cnc    | 0.09204         | -     | +      | -         | 24,25     |
| GX Cas    | 0.09297         | -     | -      | +         | 26        |
| V725 Aql  | 0.09909         | -     | +      | -         | 27        |
| MN Dra    | 0.1055          | -     | -      | +         | 28,29     |

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Many characteristics of V419 Lyr are typical of SU UMa stars. It goes into superoutburst every year or so, the eruption lasts about two weeks and has an amplitude of $\sim 3.5$ mag. Superhumps appear shortly after the beginning of the superoutburst and have a maximum amplitude of 0.3 mag, which decreases to 0.1 mag at the end of the outburst. In addition to its long orbital period, V419 Lyr is unusual in two other properties. Its superhump period derivative has one of the largest negative values known and it shows only a weak trace of secondary humps in the final stages of the superoutburst.

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