V344 Lyr: an unusual large-amplitude SU UMa-type dwarf nova with a short supercycle

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ABSTRACT

We studied the large-amplitude SU UMa-type dwarf nova V344 Lyr. A combination of our observations and reports from the Variable Star Network (VSNET) yields an extensive coverage of outbursts between 1994 July and 2001 June. The analysis of these data showed a mean supercycle length of 109.6 d. This value is one of the smallest among known SU UMa-type dwarf novae (except unusual ER UMa-type dwarf novae). The outburst amplitude of V344 Lyr (~5.5 mag) is found to be much larger than those (~3.5 ± 0.3 mag) of SU UMa-type dwarf novae with similar supercycle lengths. Such a deviation of the amplitude of V344 Lyr is difficult to explain using the inclination effect. The extreme outburst parameters of V344 Lyr would require an additional mechanism to effectively reduce the quiescent luminosity or to increase the outburst frequency.

Key words: accretion, accretion discs – stars: dwarf novae – stars: individual: V344 Lyr – novae, cataclysmic variables.

1 INTRODUCTION

Dwarf novae are a class of cataclysmic variables (CVs), which are close binary systems consisting of a white dwarf and a red dwarf secondary transferring matter via the Roche lobe overflow. Thermal instability in the resultant accretion disc is now widely believed to cause dwarf nova type outbursts (see Osaki 1996 for a review). In dwarf novae whose binary mass-ratios (q = M₂/M₁) are small enough, a different kind of instability – tidal instability – occurs (Whitehurst 1988), which is now widely believed to be a cause of superoutbursts and superhumps in SU UMa-type dwarf novae (for a recent review of SU UMa-type stars and their observational properties, see Warner 1995).

Among SU UMa-type dwarf novae, some objects show large-amplitude outbursts. Although there is evidence that outburst amplitudes of dwarf novae are known to comprise a continuum from small to large amplitudes (see a discussion in Patterson et al. 1996), these large-amplitude objects are sometimes symbolically known as TOADs (Tremendous Outburst Amplitude Dwarf Novae: Howell, Szkody & Cannizzo 1995). At the extreme end, there exist so-called WZ Sge-type dwarf novae (originally proposed by Bailey 1979; see also Downes & Margon 1981 and O’Donoghue et al. 1991). WZ Sge-type dwarf novae (and related systems) are known to show peculiar outburst characteristics among SU UMa-type dwarf novae: (i) long intervals between outbursts (WZ Sge itself has a recurrence time of 23 to 33 yr, which is the longest among all known dwarf novae), (ii) lack of, or very low, frequency of normal outbursts, in contrast to usual SU UMa-type dwarf novae, which show more abundant normal outbursts (no normal outburst has ever been observed in WZ Sge itself) and (iii) extremely long (up to ~100 d) and bright superoutbursts.

V344 Lyr is a dwarf nova that was discovered by Hoffmeister (1966). Kato (1993) detected superhumps with a period of 0.09145(2) d, which confirms that V344 Lyr is a member of SU UMa-type dwarf novae with long orbital periods. The reported range of variability (13.8–20V) makes V344 Lyr a candidate for rare large-amplitude dwarf novae with long orbital periods. As many of large-amplitude SU UMa-type dwarf novae are known to be most infrequently outbursting systems, the proposed supercycle of 240 d (Kato 1993) would make V344 Lyr an exceptional object.

In order to clarify the situation, we examined our observations and the observations between 1994 July and 2001 June, made by the VSNET Collaboration.¹

2 OBSERVATIONS AND RESULTS

2.1 Outburst cycle length and statistics

The observations by the authors of this paper and those from WZ Sge-type dwarf novae (originally proposed by Bailey 1979; see also Downes & Margon 1981 and O’Donoghue et al. 1991). WZ Sge-type dwarf novae (and related systems) are known to show peculiar outburst characteristics among SU UMa-type dwarf novae: (i) long intervals between outbursts (WZ Sge itself has a recurrence time of 23 to 33 yr, which is the longest among all known dwarf novae), (ii) lack of, or very low, frequency of normal outbursts, in contrast to usual SU UMa-type dwarf novae, which show more abundant normal outbursts (no normal outburst has ever been observed in WZ Sge itself) and (iii) extremely long (up to ~100 d) and bright superoutbursts.

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² Observations and results

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¹ http://www.kusastro.kyoto-u.ac.jp/vsnet/
VSNET were made visually, using \( V \)-magnitude calibrated comparison stars. The typical error of visual estimates was 0.2 mag, which will not affect the following discussion. The total number of observations was 1089. The number of positive observations was 209, corresponding to the outburst duty cycle of 19 per cent. Although this value may have suffered from some degree of selection bias, the large duty cycle is already unusual for a system with a large outburst amplitude. We selected outbursts from these data, which are summarized in Table 1 and Fig. 1.

Most outbursts were unambiguously classified as either normal outbursts or superoutbursts based on their duration and peak magnitudes, but the faintness of the object and the sometimes unfavourable observing conditions made some of classifications slightly ambiguous. Such outbursts are flagged as ‘?’ in Table 1.

### Table 1. Outbursts of V344 Lyr

| JD start | peak mag | length (d) | type | JD start | peak mag | length (d) | type |
|----------|----------|------------|------|----------|----------|------------|------|
| 2449537  | 14.4     | 13         | super| 2450651  | 14.3     | >8         | super |
| 2449566  | 15.0     | 1          | normal| 2450674  | 15.7     | 1\(^{a}\) | normal |
| 2449604  | 14.0     | 2          | normal| 2450689  | 15.1     | 1\(^{a}\) | normal |
| 2449629  | 14.2     | 4          | normal| 2450716  | 15.0     | 1\(^{a}\) | normal |
| 2449651  | 14.4     | 3          | normal| 2450727  | 15.0     | 3        | normal |
| 2449662  | 14.8     | 2          | normal| 2450755  | 15.2     | 2        | normal |
| 2449857  | 14.5     | 4          | normal| 2450771  | 14.4     | >4        | super? |
| 2449867  | 15.8     | 1\(^{a}\) | normal| 2450882  | 14.2     | >9        | super |
| 2449923  | 15.0     | 2          | normal| 2450992  | 14.3     | 10        | super |
| 2449934  | 14.3     | 2          | normal| 2451042  | 14.7     | 2        | normal |
| 2449946  | 14.3     | 13         | super| 2451060  | 15.3     | 1\(^{a}\) | normal |
| 2450001  | 14.6     | 3          | normal| 2451094  | 14.2     | 16        | super |
| 2450062  | 14.6     | 1\(^{a}\) | normal| 2451271  | 14.6     | 3        | normal |
| 2450184  | 14.3     | >7         | super| 2451310  | 14.4     | >8        | super |
| 2450225  | 15.2     | 1\(^{a}\) | normal| 2451406  | 14.6     | 3        | normal |
| 2450270  | 15.3     | 2          | normal| 2451416  | 15.5     | 1\(^{a}\) | normal |
| 2450290  | 14.6     | 2          | normal| 2451421  | 14.3     | 16        | super |
| 2450300  | 14.7     | 3          | normal| 2451465  | 15.1     | 1\(^{a}\) | normal |
| 2450312  | 14.7     | >3         | super?| 2451520  | 14.6     | >8        | super |
| 2450340  | 15.7     | 1\(^{a}\) | normal| 2451628  | 14.7     | >3        | super? |
| 2450370  | 14.6     | 4          | normal| 2451674  | 15.0     | 1\(^{a}\) | normal |
| 2450418  | 14.4     | >4         | super?| 2451737  | 14.6     | 1\(^{a}\) | normal |
| 2450506  | 15.5     | 1\(^{a}\) | normal| 2451795  | 15.2     | 1\(^{a}\) | normal |
| 2450514  | 15.3     | 1\(^{a}\) | normal| 2451800  | 15.2     | 4        | normal |
| 2450545  | 14.6     | >6         | super?| 2451815  | 14.5     | 2        | normal? |
| 2450585  | 15.2     | 1\(^{a}\) | normal| 2451865  | 14.6     | 1\(^{a}\) | normal |
| 2450607  | 14.9     | 2          | normal| 2452068  | 14.4     | >4        | super |
| 2450639  | 14.6     | 4          | normal|          |          |           |       |

\(^{a}\)Single observation. 
\(^{b}\)Double peaks.

![Figure 1](https://example.com/fig1.png)

**Figure 1.** Overall light curve of V344 Lyr. Superoutbursts are marked with ticks. Upper-limit observations are not plotted for simplicity.

2.2 Outburst amplitude

Because the outburst amplitude is sensitive to outburst and quiescent magnitudes, we have tried to recalibrate these values using the modern \( V \) scale. As recent outburst observations have been made using modern \( V \)-magnitude comparison stars, we have adopted \( V = 14.0 \) as the maximum magnitude. [This value is in agreement with the \( V = 14.2 \) obtained by Kato (1993). An even better agreement would be achieved if one considers that the CCD observation by Kato (1993) started a few days after the visual maximum.]

Regarding the quiescent magnitude, Hoffmeister (1966) stated that ‘the object is invisible on the Palomar Sky Survey plates’, from which an upper limit of 20 has been adopted in the literature. We have confirmed this finding by a direct inspection of paper reproductions of the Palomar Observatory Sky Survey (POSS) I plates. The object is also missing from the US Naval Observatory (USNO) A1.0 and A2.0 catalogues, which reach a limiting magnitude of 19.5. We have also found that the object is seen faintly on the digitized POSS I plates, available at the US Naval Observatory, Flagstaff Station (USNOFS) Image and Catalogue Archive, and yield a magnitude of \( R = 19.5 \pm 0.3 \), by comparison with the modern comparison stars. Because short-period dwarf novae have colours close to \( V - R = 0 \) even in quiescence, this value is considered to be a good approximation of the quiescent \( V \) magnitude.

We have also inspected the available images, on which V344 Lyr was probably recorded at or close to its minimum (the object was
recorded in outburst on POSS II plates). The images taken at Ouda Station, Kyoto University (Ohtani et al. 1992), on 1991 February 23 yield $I_c = 17.8 \pm 0.2$. An unfiltered CCD image taken on 1996 July 17 shows no hint of the object down to 19.0 mag. The Guide Star Catalog plates, as given in Downes & Shara (1993), show the object at 18–19 mag. The above results are summarized in Table 2. These results may suggest a considerable variation of the quiescent magnitude, but it would not be surprising that the object may not have completely reached quiescence in some observations, when one takes the large outburst duty cycle of 19 per cent into account. From these observations, we adopted $5.5 \pm 0.3$ mag for the outburst amplitude of V344 Lyr.

### Table 2. Quiescent magnitudes of V344 Lyr.

| Source             | Year    | Magnitude | Band   |
|--------------------|---------|-----------|--------|
| DSS I              | 1955.555| 19.5 ± 0.3| POSS red |
| GSC plate scan     | 1982.390| 18–19     | V      |
| This study         | 1991.147| 17.8 ± 0.2| $I_c$  |
| This study         | 1996.543| 19.0      | unfiltered CCD |

* System close to $R_c$.

### Figure 2. The light curve of V344 Lyr between JD 2450860 (1998 February 16) and JD 2451152 (1998 December 5). The ‘v’ marks represent upper-limit observations. The durations and brightness of the marked outbursts qualify them as superoutbursts, confirming the short supercycle of ~110 d. Note that the marks on the superoutbursts correspond to the earliest detection of each superoutburst. The third superoutburst was detected during its rise to maximum. Two short, fainter outbursts (normal outbursts) occurring on JD 2451042 and 2451060 were detected between the second and third superoutbursts.

### Table 3. Properties of SU UMa-type dwarf novae with short supercycles.

| Name    | $P_{SH}$ (d) | Max | Min | Amp | $T_s^d$ (d) |
|---------|--------------|-----|-----|-----|-------------|
| RZ LMi  | 0.05946      | 14.2| 17.0| 2.8 | 19          |
| DI UMa  | 0.0555       | 15.1| 18.0| 2.9 | 25          |
| ER UMa  | 0.06573      | 12.9| 15.8| 2.9 | 43          |
| V1159 Ori | 0.06861      | 12.8| 15.4| 2.6 | 44.6–53.3   |
| IX Dra  | 0.06700      | 15.0| 17.5| 2.5 | 45.7–53     |
| SS UMi  | 0.0699       | 13.6| 16.7| 3.1 | 84.7        |
| NY Ser  | 0.1064       | 14.3| 18.2| 3.7 | 70–100      |
| V503 Cyg | 0.08101      | 13.95| 17.5| 3.5 | 89          |
| V344 Lyr | 0.09145      | 14.0| 19.5| 5.5 | 109.6       |
| V2 And  | 0.07411      | 13.9| 17.5| 3.6 | 100–140     |
| V1504 Cyg | 0.0690      | 13.8| 17.4| 3.6 | 137         |
| VZ Pyx  | 0.07576      | 11.8| 15.2| 3.4 | 152         |
| SU UMa  | 0.0788       | 11.3| 15.0| 3.7 | 160         |
| WX Hya  | 0.07737      | 11.4| 14.9| 3.5 | 174         |
| VW Hya  | 0.07714      | 8.7 | 13.8| 5.1 | 179         |
| IR Gem  | 0.07094      | 11.4| 16.3| 4.9 | 183         |
| V1113 Cyg | 0.0792      | 13.6| 18.6| 5.0 | 189.8       |
| TY PsA  | 0.08765      | 11.8| 15.9| 4.1 | 202         |
| VY Lyr  | 0.0756       | 12.4| 18.4| 6.0 | 210         |
| TT Boo  | 0.07811      | 12.7| 19.2| 6.5 | 245         |
| RZ Sge  | 0.07042      | 12.2| 17.4| 5.2 | 266         |
| SX LMi  | 0.06850      | 13.3| 16.8| 3.4 | 279         |
| Z Cha   | 0.07740      | 12.7| 15.6| 2.9 | 287         |

$^a$Amplitude (mag). 
$^b$Length of supercycle.

#### 3.2 Outburst amplitude versus supercycle length

As shown in Section 3.1, the supercycle of V344 Lyr is 109.6 d, which is exceptionally short for an SU UMa-type dwarf nova with a large outburst amplitude. Table 3 lists the properties of SU UMa-type dwarf novae with well-established short supercycle lengths ($T_s < 300$ d). The source data are from Nogami et al. (1997), with recent revisions and additions mentioned in the individual notes. Excluding SX LMi (unusual low-amplitude system as discussed by Nogami et al. 1997), Z Cha (high-inclination eclipsing system) at the lower right-hand part of Fig. 3, and V344 Lyr, we found the following good correlation between $T_s$ and outburst amplitude ($A$) for systems $T_s > 80$ d (i.e. normal SU UMa stars):

$$A = 2.041 \log(T_s) - 0.4. $$

Most remarkable is that the outburst amplitudes of SU UMa-type dwarf novae are confined to a narrow range (3.1 to 4.0 mag) for systems between $T_s = 84$ and $T_s = 174$, except V344 Lyr. This distribution has a mean amplitude of 3.5 mag and a standard deviation of 0.3 mag. The observed amplitude of V344 Lyr (5.5 ± 0.3 mag) is 7 ± 1σ larger than the average. Even adopting a conservative upper limit of the minimum magnitude of 18.5 (from GSC plate scan), the value is still 3σ above the average.

Warner (1987) presented, with an assumption of an optically thick disc, a formulation of the dependence of the absolute $V$ magnitude on the system inclination. A disc seen at nearly edge-on ($i = 85^\circ$) is 3.5 mag brighter than the pole-on ($i = 0^\circ$) view.

2The limit has been chosen for two reasons: (i) $T_s$ tends to be stable in frequently outbursting systems (i.e. short $T_s$ systems), the extreme cases being ER UMa stars. Systems with superoutbursts less than once per year often do not have a fixed $T_s$. (ii) Because of unavoidable seasonal observational gaps, long $T_s$ systems have uncertainties in unambiguously identifying $T_s$. 

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3.3 Notes on individual objects in Table 3

[DI UMa] – Large change of $T_s$ has been inferred (Fried et al. 1999). The value given in the table corresponds to the most stable outbursting period (Kato, Nogami & Baba 1996; Kato et al., in preparation).

[V1159 Ori] – Newly determined $T_s$ from Kato (2001a).

[IX Dra] – Newly discovered ER UMa-type dwarf nova. The data are from Ishioka et al. (2001).

[SS UMi] – $T_s$ from Kato et al. (2000). The maximum magnitude of $V = 12.6$ (Mason et al. 1982) was probably in error; no such bright outburst has been observed in plate searches (see also Richter 1989; Kato et al. 1998). The maximum magnitude is taken from the recent VSNET observations.

[FO And] – $T_s$ and maximum magnitude have been revised using VSNET observations.

[VZ Pyx] – $T_s$ listed in Kato & Nogami (1997) and Nogami et al. (1997) was erroneous. The new $T_s$ is determined from VSNET observations, which show very regular supercycles, resembling those of YZ Cnc. The maximum and minimum magnitudes are also from VSNET observations, based on the newly calibrated $V$-magnitude sequence.

[SU UMa] – Typical $T_s$ is given. The system sometimes shows reduced outburst and supuroutburst frequencies (Rosenzweig et al. 2000).

[WX Hyi] – Typical $T_s$, as measured from VSNET observations between 1996 and 1998, is given. The system is known to sometimes show a reduced frequency of superoutbursts.

[IR Gem] – Revised $T_s$ based on the analysis of the VSOLJ data. Revised superhump period from Kato (2001b). The maximum and minimum magnitudes are from VSNET observations and Misselt (1996), respectively.

[V1113 Cyg] – Mean $T_s$ from Kato (2001c), which reported a variation of supercycles between 169 and 229 d. Kato (2001c) reported rather unusual outburst characteristics, having a low ratio of (normal outbursts)/(superoutbursts). The minimum magnitude given is our new calibration of the DSS 1, while Liu et al. (1999) reported a rough estimate of $V = 20.8$ from their spectroscopic observation. The system requires further detailed study in quiescence.

[TY PsA] – Revised $T_s$ and maximum magnitude from VSNET observations.

[AY Lyr] – Revised $T_s$ and maximum magnitude from VSNET observations. The minimum magnitude is taken from Misselt (1996).

[SX LMi] – Mean $T_s$ from Kato (2001d), which showed a variation of supercycles between 250 and 312 d.

The following objects in Nogami et al. (1997) have been excluded from the list:

[CI UMa] – Nogami & Kato (1997) listed a possible supercycle of 140 d, while recent reports to VSNET show that the intervals are typically longer and outbursts occur rather irregularly (see also Kato et al. 2000).

[V630 Cyg] – Nogami et al. 1997 listed a possible supercycle of 290 d. Recent study by Nogami et al. (2001) indicates that supercycles vary more irregularly.

4 SUMMARY

We observed the large-amplitude SU UMa-type dwarf nova V344 Lyr. Combined with reports to VSNET, we have succeeded in determining its mean supercycle length as 109.6 d. This value is one of the smallest among known SU UMa-type dwarf novae (except unusual ER UMa-type dwarf novae). The observed outburst amplitude (5.5 ± 0.3 mag) in V344 Lyr is found to be exceptionally large for a system with such a short supercycle. Because a short supercycle strongly suggests a relatively high mass-transfer rate, the extreme outburst parameters of V344 Lyr would require a mechanism to effectively reduce the quiescent luminosity or to increase the outburst frequency.
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