Dramatic Changes in the Outburst Properties in V503 Cygni

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Abstract

We examined the VSNET light curve of the unusual SU UMa-type dwarf nova V503 Cyg which is known to show a short (89 d) supercycle length and exceptionally small (a few) normal outbursts within a supercycle. In 1999–2000, V503 Cyg displayed frequent normal outbursts with typical recurrence times of 7–9 d. The behavior during this period is characteristic to an usual SU UMa-type dwarf nova with a short supercycle length. On the other hand, V503 Cyg showed very infrequent normal outbursts in 2001–2002. The remarkable alternations of the outbursting states in V503 Cyg support the presence of mechanisms of suppressing normal outbursts and premature quenching superoutbursts, which have been proposed to explain some unusual SU UMa-type outbursts. The observed temporal variability of the suppressing/quenching mechanisms in the same object suggests that these mechanisms are not primarily governed by a fixed system parameter but more reflect state changes in the accretion disk.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (V503 Cygni) — stars: novae, cataclysmic variables

1. Introduction

ER UMa stars are a still enigmatic small subgroup of SU UMa-type dwarf novae [for a review of dwarf novae, see Osaki (1996)], which have extremely short supercycle lengths (\(T_s\), the interval between successive superoutbursts) of 19–50 d [for a review, see Kato et al. (1999)] and regular occurrence of superoutbursts. Only five definite members have been recognized up to now: ER UMa (Kato, Kunjaya 1995, Robertson et al. 1995, Misselt, Shafter 1995); V1159 Ori (Nogami et al. 1995a, Patterson et al. 1995); RZ LMi (Robertson et al. 1995, Nogami et al. 1995b); DI UMa (Kato et al. 1996); and IX Dra (Ishioka et al. 2001). Some helium-transferring cataclysmic variables have become recognized as “helium counterparts” of ER UMa stars [CR Boo: Kato et al. (2000b); V803 Cen: Kato et al. (2000c), Kato et al. (2001b)]. From a theoretical side, ER UMa stars have been understood as a smooth extension of normal SU UMa-type dwarf nova toward higher mass-transfer rates (\(M\)) (Osaki 1995a). The exact origin of such a high mass-transfer rate is still a mystery. Even considering a higher mass-transfer rate, the shortest period systems (RZ LMi and DI UMa) are difficult to explain without a special mechanism of prematurely quenching a superoutburst (Osaki 1995b).

In recent years, there have been an alternative attempt to explain the ER UMa-type phenomenon. Hellier (2001) tried to explain the ER UMa-type phenomenon by considering a decoupling between the thermal and tidal instabilities [see Osaki (1989) for details of the thermal-tidal instability model] under extremely small binary mass-ratio (\(q=M_2/M_1\)) conditions. Hellier (2001) speculated that repeated post-superoutburst rebrightenings\(^1\) in WZ Sge-type dwarf novae (hereafter WZ Sge stars) or large-amplitude SU UMa-type dwarf novae (e.g. Kuulkers 2000; see Kato et al. 2001a) for a recent observational review of WZ Sge-type stars). Buat-Ménard et al. (2001) tried to explain ER UMa-type phenomenon by (rather arbitrary) introducing an inner truncation of the accretion disk and irradiation on the secondary star on a numerical model developed by Hameury et al. (2000). Buat-Ménard, Hameury (2002) further tried to explain the unification idea by Hellier (2001) using the same scheme as in Buat-Ménard et al. (2001). Although the results partly reproduced the characteristics of ER UMa stars and WZ Sge stars, they failed to quantitatively reproduce the light curves of these dwarf novae.

From the observational side, the existence of a gap between distributions of ER UMa stars and “usual” SU UMa-type dwarf novae has been a challenge. The shortest known \(T_s\) in usual SU UMa-type dwarf novae had been 130 d (YZ Cnc, see also Table 1 in Nogami et al. 1997) at the time of the initial proposition of ER UMa stars. Although further works have slightly shortened this minimum \(T_s\) (SS UMi: 84.7 d, Kato et al. 2000a); BF Ara: 83.4 d, Kato et al. 2001c), there still remains a undisputed gap. In addition to these usual SU UMa-type dwarf novae with the shortest \(T_s\)’s, there exists a seemingly different population

\(^1\) These phenomena are sometimes referred to as “echo outbursts,” but we avoid using this terminology because this idea was first proposed to describe the “glitches” or “reflares” in soft X-ray transients (SXTs) (Augusteijn et al. 1993). In SXTs, hard-soft transition is considered to be more responsible for the initially claimed phenomenon (Mineshige 1996), which is clearly different from dwarf nova-type rebrightenings.
of SU UMa-type dwarf novae with short $T_s$’s, but with infrequent normal outbursts. V503 Cyg [$T_s = 89$ d, only a few normal outbursts in a supercycle (Harvey et al. 1995)] and CI UMa [$T_s \sim 140$ d, infrequent normal outbursts (Nogami, Kato 1997); $T_s$ variable? (Kato et al. 2002)] are the best-known examples. The relation, however, between these objects and ER UMa stars (and short $T_s$ usual SU UMa-type dwarf novae) are unknown. In most recent years, some instances of strong $T_s$ variations have been reported in ER UMa stars (Fried et al. 1999, Kato 2001a). In this letter, we report on the dramatic changes in the outburst properties in V503 Cyg.

2. Observation and Analysis

We examined the observations of V503 Cyg posted to VSNET Collaboration, and found an appreciable change of the outburst properties. The observations used V-band comparison stars, and typical errors of individual estimates are smaller than 0.3 mag, which will not affect the following discussion. The object has been well sampled by many observers around the world except for periods of solar conjunctions.

Table 1 lists the observed outbursts since 1997. The outburst lengths listed in the table approximately correspond to the durations above $V \sim 15.5$. Although occasional observational gaps introduced an uncertainty of a few days, most of these superoutbursts were well recorded. Many of normal outbursts during the favorably observed seasons were recorded, although some outbursts must have been missed. In order to estimate the numbers of missed outbursts, we performed Monte-Carlo simulations. The fractions of missing simulated 1000 normal outbursts (the maximum magnitude and the rate of decline have been adjusted to those of actual outbursts) were 10%, 18% and 30% for the three representative epochs shown in figure 1. These fractions of missing normal outbursts will not affect the discussion given in section 3.

3. Discussion

In the standard disk instability model, the recurrence time of normal outbursts ($T_n$) is mainly governed by the diffusion process, while $T_s$ represents the increasing rate of net angular momentum in the accretion disk (Ichikawa, Osaki 1994). If the quiescent viscosity parameter has a fixed value between various SU UMa-type dwarf novae, both $T_n$ and $T_s$ are unique functions of $M$ (Ichikawa, Osaki 1994). This relation has been observationally confirmed in most of SU UMa-type stars (Warner 1995). V503 Cyg apparently violates this relation in its low frequency of normal outbursts (figure 1, upper panel), and several other stars (V344 Lyr; SX LMi) have been proposed to be analogous to V503 Cyg (Kato 2001b, Kato et al. 2002). There must be an unknown suppression mechanism of normal outbursts in these systems.

In 1999–2000, V503 Cyg showed a very frequent occurrence of normal outbursts (minimum $T_n \sim 7–9$ d, figure 1, middle panel). This $T_n$ is just what is expected for a $T_s = 89$ d usual SU UMa-type dwarf nova (Warner 1995). This fact indicates that the usually outbursting SU UMa-type state and unusually outbursting (in the sense of low frequency of normal outbursts) V503 Cyg-type state are interchangeable. Since $T_s$ during this period was not appreciably different from the canonical $T_s = 89$ d, there should have not been an appreciable change in the $M$. The suppression mechanism of normal outbursts must have been somehow “unlocked” during this period.

In 2001–2002, V503 Cyg showed another different aspect (figure 1, lower panel). During this period, the number of normal outbursts in a supercycle dramatically decreased to $\sim 1$. There is some hint of alternating occurrence of a superoutburst and a normal outburst with a period of 40–80 d. Such a sequence of outbursts is only known in rarely outbursting SU UMa-type dwarf novae [cf.
Table 1. Outbursts of V503 Cyg since 1997.

| JD start | Peak mag | Length | Type | JD start | Peak mag | Length | Type |
|---------|----------|--------|------|---------|----------|--------|------|
| 2450545 | 14.2     | 3      | normal | 2451519 | 14.4     | 2      | normal |
| 2450574 | 13.7     | 3      | normal | 2451531 | 13.8     | 10     | super |
| 2450601 | 13.1     | 14     | super  | 2451641 | 14.5     | 1*     | normal |
| 2450643 | 14.4     | 2      | normal | 2451666 | 14.5     | 2      | normal |
| 2450669 | 14.1     | 3      | normal | 2451673 | 14.4     | 3      | normal |
| 2450697 | 13.1     | 13     | super  | 2451691 | 14.2     | 3      | normal |
| 2450719 | 14.5     | 2      | normal | 2451704 | 13.4     | 12     | super |
| 2450758 | 14.3     | 1*     | normal | 2451727 | 13.7     | 2      | normal |
| 2450776 | 13.8     | 12     | super  | 2451736 | 14.0     | 2      | normal |
| 2450896 | 14.3     | 2      | normal | 2451744 | 14.6     | 3      | normal |
| 2450952 | 13.3     | 10     | super  | 2451753 | 15.6     | 1      | normal |
| 2450989 | 14.4     | 3      | normal | 2451785 | 13.4     | 11     | super |
| 2451018 | 14.1     | 3      | normal | 2451813 | 14.8     | 2      | normal |
| 2451051 | 13.3     | >8     | super  | 2451819 | 14.8     | 2      | normal |
| 2451072 | 14.6     | 2      | normal | 2451826 | 14.5     | 2      | normal |
| 2451124 | 13.4     | 12     | super  | 2451837 | 14.3     | 2      | normal |
| 2451220 | 14.0     | 1*     | normal | 2451848 | 13.6     | 1*     | normal |
| 2451237 | 14.0     | 1*     | normal | 2451865 | 13.8     | 2      | normal |
| 2451323 | 14.5     | 3      | normal | 2451873 | 13.6     | 11     | super |
| 2451337 | 14.4     | 3      | normal | 2451964 | 14.7     | 1*     | normal |
| 2451348 | 14.3     | 1      | normal | 2452014 | 14.1     | 1*     | normal |
| 2451359 | 14.4     | 1*     | normal | 2452046 | 13.5     | 13     | super |
| 2451372 | 13.6     | 12     | super  | 2452114 | 13.3     | 3      | normal |
| 2451406 | 14.4     | 2      | normal | 2452135 | 13.0     | 14     | super |
| 2451428 | 14.1     | 3      | normal | 2452176 | 13.9     | 3      | normal |
| 2451435 | 14.2     | 2      | normal | 2452231 | 13.4     | 10     | super |
| 2451453 | 13.7     | 13     | super  | 2452278 | 13.7     | 2      | normal |
| 2451479 | 14.4     | 1*     | normal | 2452321 | 13.8     | >5     | normal |
| 2451485 | 14.4     | 2      | normal | 2452397 | 13.8     | 19†    | super |
| 2451495 | 14.4     | 2      | normal | 2452466 | 13.7     | 3      | normal |

* Single observation.
† Brightening at the end. May have been two separate outbursts.

SW UMa, V844 Her cf. Kato, Uemura (2000) for a discussion, and is unprecedented in short $T_s$ systems. During this period, some normal outbursts have comparable peak magnitudes to those of superoutbursts. Some of superoutbursts showed rather short durations, which seems to be incompatible with a high $\dot{M}$ necessary to reproduce the short $T_s$ (Osaki 1995a). These findings suggest that premature quenching of superoutbursts, as proposed by Osaki (1995b) and Hellier (2001), indeed occurred during this period, although V503 Cyg (orbital period = 0.0757 d) is unlikely to have a small $q$ required in Osaki (1995b) and Hellier (2001). The overall light curve more or less resembles that of CI UMa (Kolotovkina 1979, Nogami, Kato 1997).

Although exact mechanisms have not been yet identified, the present remarkable alternations between the outbursting states in V503 Cyg support the presence of mechanisms of suppressing normal outbursts and premature quenching superoutbursts. The most important finding is that the effects of these mechanisms are temporarily variable even in the same object, and are not a fixed character of a certain system. This finding suggests that the shortest $T_s$ usual SU UMa stars and unusual V503 Cyg-like stars can represent different aspects of the same system. Among ER UMa stars, DI UMa can be a similar system with systematic state changes (Fried et al. 1999). The observed temporal variability of the suppressing/quenching mechanisms in the same object suggests that these mechanisms are not primarily governed by a fixed system parameter [i.e. mass of the white dwarf (Buat-Ménard et al. 2001); $q$ (Hellier 2001) etc.] but more reflect state changes in the accretion disk.

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References

Augusteijn, T., Kuulkers, E., & Shaham, J. 1993, A&A, 279, L13
Buat-Ménard, V., & Hameury, J.-M. 2002, A&A, 386, 891
Buat-Ménard, V., Hameury, J.-M., & Lasota, J.-P. 2001, A&A, 366, 612
Fried, R. E., Kemp, J., Patterson, J., Skillman, D. R., Retter, A., Leibowitz, E., & Pavlenko, E. 1999, PASP, 111, 1275
Hameury, J.-M., Lasota, J.-P., & Warner, B. 2000, A&A, 353, 244
Harvey, D., Skillman, D. R., Patterson, J., & Ringwald, F. A. 1995, PASP, 107, 551
Hellier, C. 2001, PASP, 113, 469
Ichikawa, S., & Osaki, Y. 1994, in Theory of Accretion Disks-2, ed. W. J. Duschl, J. Frank, F. Meyer, E. Meyer-Hofmeister, & W. M. Tscharnuter (Dordrecht: Kluwer Academic Publishers), 169
Ishioka, R., Kato, T., Uemura, M., Iwamatsu, H., Matsumoto, K., Martin, B., Billings, G. W., & Novák, R. 2001, PASJ, 53, L51
Kato, T. 2001a, PASJ, 53, L17
Kato, T. 2001b, Inf. Bull. Variable Stars, 5071
Kato, T., Hanson, G., Poyner, G., Muylleart, E., Reszelski, M., & Dubovsky, P. A. 2000a, Inf. Bull. Variable Stars, 4932
Kato, T., & Kunjaya, C. 1995, PASJ, 47, 163
Kato, T., Nogami, D., & Baba, H. 1996, PASJ, 48, L93
Kato, T., Nogami, D., Baba, H., Hanson, G., & Poyner, G. 2000b, MNRAS, 315, 140
Kato, T., Nogami, D., Baba, H., Masuda, S., Matsumoto, K., & Kunjaya, C. 1999, in Disk Instabilities in Close Binary Systems, ed. S. Mineshige, & J. C. Wheeler (Tokyo: Universal Academy Press), 45
Kato, T., Poyner, G., & Kimnumen, T. 2002, MNRAS, 330, 53
Kato, T., Sekine, Y., & Hirata, R. 2001a, PASJ, 53, 1191
Kato, T., Stubbings, R., Monard, B., & Pearce, A. 2000c, Inf. Bull. Variable Stars, 4915
Kato, T., Stubbings, R., Monard, B., Pearce, A., & Nelson, P. 2001b, Inf. Bull. Variable Stars, 5091
Kato, T., Stubbings, R., Pearce, A., Nelson, P., & Monard, B. 2001c, Inf. Bull. Variable Stars, 5119
Kato, T., & Uemura, M. 2000, Inf. Bull. Variable Stars, 4902
Kolotovkina, S. A. 1979, Perem. Zvezdy Pril., 3, 665
Kuulkers, E. 2000, New Astron. Rev., 44, 27
Mineshige, S. 1996, PASJ, 48, 93
Misselt, K. A., & Shafter, A. W. 1995, AJ, 109, 1757
Nogami, D., & Kato, T. 1997, PASJ, 49, 109
Nogami, D., Kato, T., Masuda, S., & Hirata, R. 1995a, Inf. Bull. Variable Stars, 4155
Nogami, D., Kato, T., Masuda, S., Hirata, R., Matsumoto, K., Tanabe, K., & Yokoo, T. 1995b, PASJ, 47, 897
Nogami, D., Masuda, S., & Kato, T. 1997, PASP, 109, 1114
Osaki, Y. 1989, PASJ, 41, 1005
Osaki, Y. 1995a, PASJ, 47, L11
Osaki, Y. 1995b, PASJ, 47, L25
Osaki, Y. 1996, PASP, 108, 39
Patterson, J., Jablonski, F., Koen, C., O'Donoghue, D., & Skillman, D. R. 1995, PASP, 107, 1183
Robertson, J. W., Honeycutt, R. K., & Turner, G. W. 1995, PASP, 107, 443
Warner, B. 1995, Ap&SS, 226, 187