WZ Sge-Type Star V592 Herculis

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Abstract

We observed the entire course of the 1998 outburst of V592 Her, which was originally reported as a nova in 1968. We have been able to construct a full light curve of the outburst, which is characterized by a rapid initial decline (0.98 mag d$^{-1}$), which smoothly developed into a plateau phase with a slower linear decline. We detected superhumps characteristic to SU UMa-type dwarf novae $\sim$7 d after the optical maximum. The overall behavior of the light curve and the development of superhumps were characteristic to a WZ Sge-type dwarf nova. Combined with the past literature, we have been able to uniquely determine the superhump period to be 0.05648(2) d. From this period, together with a modern interpretation of the absolute magnitude of the outburst light curve, we conclude that the overall picture of V592 Her is not inconsistent with a lower main-sequence secondary star in contrast to a previous claim that V592 Her contains a brown dwarf.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (V592 Herculis) — stars: novae, cataclysmic variables

1. Introduction

WZ Sge-type dwarf novae are a still enigmatic class of SU UMa-type dwarf novae [for recent summaries of dwarf novae and SU UMa-type dwarf novae, see Osaki (1996) and Warner (1995b), respectively], which is characterized by a long ($\sim 10$ yr) outburst recurrence time and a large ($\sim 8$ mag) outburst amplitude (cf. Bailey 1979; Downes, Margon 1981; Patterson et al. 1981; O’Donoghue et al. 1991; Kato et al. 2001b).

In recent years, the secondary stars (mass-donor stars) of WZ Sge-type dwarf novae, or dwarf novae with extremely large outbursts amplitudes (TOADs, Howell et al. 1995), have been regarded as promising candidates for brown dwarfs (Howell et al. 1997; Politano et al. 1998; Ciardi et al. 1998; Patterson 2001; Howell, Ciardi 2001). The existence of a brown-dwarf secondary star has been also considered to play an important role in realizing an extremely low quiescent viscosity of WZ Sge-type stars required (Smak 1993; Osaki 1995) from the disk-instability theory (Meyer-Hofmeister et al. 1998; Mineshige et al. 1998)\(^1\) Observational confirmation of cataclysmic variables (CVs) with brown dwarf secondaries is also important in that it can provide an independent estimate of the upper limit of the age of the Universe (Politano et al. 1998; Szkody et al. 2002b). In particular, Howell, Ciardi 2001 claimed the direct spectroscopic detection of a brown dwarf in LL And, but inconsistent arguments, however, exist against the extremely low quiescent viscosity. Lasota et al. (1995), Warner et al. (1996) assuming evaporation/truncation of the inner disk are the best examples. Hameury et al. (1997) and Buat-Ménard, Hameury (2002) presented slight modifications of these ideas. The discovery of a WZ Sge-type phenomenon in a long-period system (Ishikawa et al. 2001) suggests that the existence of a brown-dwarf secondary is not a necessary condition for manifestation of the WZ Sge-type phenomenon.
tency in this interpretation has been later found (Howell et al. 2002). Mennickent et al. (2001) reported a discovery of a CV with a brown dwarf based on radial velocity studies. V592 Her is another object in which the existence of a brown dwarf has been claimed (van Teeseling et al. 1999).

V592 Her was discovered as a possible fast nova in 1968 on Sonneberg plates (Richter 1968). The observed maximum was $m_{\text{pg}} = 12.3$. Although there was a gap in the 1968 observation, the outburst lasted at least for 30 d. Richter (1968) reported that the object was exceptionally blue based on a comparison between quasi-simultaneously taken blue- and yellow-sensitive plates. Based on this conspicuously blue color at maximum, Duerbeck (1987) suspected that the object may be either a dwarf nova or an X-ray nova resembling V616 Mon.

Richter (1991) further studied Sonneberg plates, and discovered a second outburst in 1986. The recorded maximum of the 1986 outburst was $m_{\text{pg}} = 13.6$ (1986 May 12). The limited coverage of this 1986 outburst made it difficult to draw a conclusion on the nature of this outburst. The star has been intensively monitored by visual observers, members of the Variable Star Observers League in Japan (VSOLJ) since 1986 February. The absence of visual detection of the 1986 May outburst suggests that the outburst was fainter than the 1968 one, or the brightness peak lasted for a very short time. In spite of the intensive world-wide efforts, no further outburst had been detected until 1998.

On 1998 August 26.835 UT, Timo Kinnunen detected the object in outburst at $m_v = 12.0$ (vsnet-alert 2067). He also noted a 0.5 mag variation within 0.08 d. The last negative observation (fainter than 13.2) was made by Patrick Schmeer on August 25.899 UT. The object was reported to fade by 0.5–1.0 mag within 0.08 d. The Ceccano observations were done using an unfiltered ST-7 camera attached to a 25-cm Schmidt-Cassegrain telescope. The magnitudes of the variable were measured using the same comparison as above, except on September 22 when GSC 1518.756 ($V = 15.32, B - V = +0.71$) and GSC 1518.662 ($V = 14.46, B - V = +0.66$) were used as the primary comparison and check stars, respectively. The Ceccano observations were done using an unfiltered ST-7 camera attached to a 28-cm Schmidt-Cassegrain telescope. The comparison stars were the same as in the Kyoto observations. The zero-point adjustments between the observations were made using common comparison stars, Henden photometric sequence and wide-field CCD images taken on 1993 March 22 at Ouda Station (Ohtani et al. 1992). The resultant magnitudes were converted to a common system close to $R_c$, adopting $R_c = 11.21$ for GSC 1518.1312. Since outbursting dwarf novae are known to have colors close to $B - V = 0$, the expected inaccuracy of zero-points caused by different color responses of different CCDs will not affect the following analysis.

Barycentric corrections to the observed times were applied before the following analysis. The log of observations is summarized in table 1.

### 3. Astrometry

An initial astrometric result from an outburst image was reported by Masi (1998), who reported J2000.0 coordinates of $16^h30^m56^s42, +21^\circ16'58".53$. Since a discrepancy from the coordinates measured from the 1968 outburst photograph suggested a significant proper motion (van Teeseling et al. 1999), we remeasured the available CCD images on a modern astrometric grid.

The resultant astrometry from the outburst CCD image by GM (epoch = 1998.657) is $16^h30^m56^s42, +21^\circ16'58".60$ (J2000.0, grid GSC-2.2, fitting error 0".15), which is consistent with the value of Masi (1998) (grid USNO-A1.0). From the DSS2 blue plate (epoch = 1994.420) we obtained $16^h30^m56^s42, +21^\circ16'58".76$ on the same grid (fitting errors 0".10). These values are almost identical to the position of candidate star No. 1 in Duerbeck (1987) ($16^h30^m56^s43, +21^\circ16'58".5$, precessed to J2000.0). Other available plate scans do not reveal this object with enough detail to perform astrometry.

From our measurements only, the upper limit of the
proper motion is $0.06 \text{ yr}^{-1}$, and Duerbeck's position (prior to 1986) suggests that it would be much smaller. On the other hand, the position of V592 Her in quiescence reported by van Teeseling et al. (1999) ($16^h30^m56.3^s \pm 0.04^s, +21^\circ16'57.9'' \pm 0.6'', \text{epoch} = 1997.589$) is incompatible with these values, especially in the Right Ascension.

An inspection of POSS I blue plate scan (epoch = 1955.385) shows a faint object about $5''$ north of the above measured position. If it is really V592 Her, it seems to favor the presence of a proper motion in the contrary direction to what was reported in van Teeseling et al. (1999). We conclude that the claimed presence of a high proper motion is still controversial and suggest that the measurements of the 1968 outburst plates need to be reexamined using original plate material.

4. Result and Discussion

4.1. Overall Outburst Light Curve

Figure 1 shows the light curve of the 1988 superoutburst of V592 Her drawn from visual observations reported to VSNET. Large and small dots represent positive and negative (upper limit) observations, respectively. Open circles with error bars represent nightly averaged Kyoto CCD observations (table 1). The overall light curve is characterized by the presence of a sharp maximum ($t = 0$, JD $2451052 \pm 1 \text{ d}$) followed by a rapid decay. The decay became slower as the object faded, and smoothly evolved into a gradually fading stage (plateau phase). Between $t = 21$ and $t = 25$, the object experienced a sudden drop by $3.4 \pm 0.5 \text{ mag}$. The early development of the light curve more resembles those of very fast novae rather than those of usual SU UMa-type dwarf novae, which are characterized by the presence of a linear (exponential in flux scale) fading at a rate of $0.03–0.16 \text{ mag d}^{-1}$ (cf. Warner 1985; see also Kato et al. 2002 for a summary of recent well-documented examples). The sudden fading between $t = 21$ and $t = 25$ is characteristic of the termination of a superoutburst in an SU UMa-type star. The later part of the outburst ($7 \leq t \leq 25$) is more characteristic of a usual SU UMa-type superoutburst while the initial part is more unusual.

Similar departures of early light curves from the “canonical” light curve of SU UMa-type superoutbursts is rather commonly seen in WZ Sge-type outbursts. In WZ Sge itself (e.g. Ortolani et al. 1980; Patterson et al. 1981), there seems to have been such a sharp initial peak.$^6$ Among

| 1998 Date | Start–End$^*$ | Exp(s) | N | Mean mag$^†$ | Error | Obs$‡$ |
|-----------|---------------|--------|---|--------------|-------|-------|
| Aug. 30   | 55.886–55.959 | 30     | 136 | 14.33        | 0.01  | G     |
| 31        | 57.308–57.393 | 90     | 53  | 14.47        | 0.01  | M     |
| Sep. 1    | 57.888–57.893 | 30     | 8   | 14.51        | 0.02  | G     |
| 2         | 58.868–58.969 | 30     | 126 | 14.68        | 0.01  | G     |
| 3         | 59.859–59.980 | 30     | 194 | 14.73        | 0.02  | M     |
| 6         | 62.889–62.965 | 30     | 236 | 15.13        | 0.01  | G     |
| 7         | 63.865–63.950 | 30     | 149 | 15.25        | 0.02  | M     |
| 8         | 64.999–65.063 | 30     | 149 | 15.25        | 0.02  | M     |
| 9         | 65.921–65.048 | 30     | 158 | 15.60        | 0.04  | K     |
| 10        | 66.924–67.026 | 30     | 73  | 15.74        | 0.02  | G     |
| 11        | 67.939–68.042 | 30     | 41  | 15.74        | 0.02  | K     |
| 12        | 68.919–69.036 | 30     | 235 | 15.65        | 0.04  | K     |
| 13        | 69.896–69.913 | 30     | 31  | 15.71        | 0.01  | G     |
| 14        | 69.914–70.038 | 30     | 213 | 15.83        | 0.05  | K     |
| 15        | 71.950–71.972 | 30     | 35  | 15.76        | 0.06  | K     |
| 16        | 72.877–72.937 | 30     | 98  | 15.96        | 0.01  | G     |
| 17        | 72.930–73.036 | 30     | 110 | 15.78        | 0.05  | K     |
| 20        | 76.922–77.041 | 30     | 195 | 19.18        | 0.46  | K     |
| 22        | 78.881–78.907 | 175$§$ | 7   | 18.74        | 0.09  | G     |
| Oct. 2    | 88.911–88.990 | 30     | 153 | 20.71        | 1.99  | K     |
| 3         | 89.927–90.006 | 30     | 82  | 17.86        | 0.68  | K     |
| 4         | 90.917–90.994 | 30     | 152 | 19.02        | 0.66  | K     |

$^*$ BJD$–2451000$.

$†$ System close to $R_c$.

$‡$ G (Garradd), M (Masi), K (Kyoto team).

$§$ Each image is a stack of five 35 s exposures.

$^6$ There exists an argument against the sharp, initial peak recorded in the past observations, because these feature were recorded on blue-sensitive photographs, which had a different sensitivity from visual observations. See also Kato et al. (2001b).
well-observed WZ Sge-type outbursts, the present V592 Her most clearly showed this feature.

Such a deviation from a linear (exponential in flux scale) decay in a WZ Sge-type outburst is shown to be naturally understood as a consequence of a rapid viscous depletion of the large amount of stored gas during the initial stage of a WZ Sge-type outburst (Osaki 1995; see also Cannizzo 1993 for a basic model). Cannizzo (2001) recently successfully modeled the light curve of the 2001 superoutburst of WZ Sge with this mechanism. Cannizzo et al. (2002) showed that this mechanism also worked in a system with a long orbital period. The case of V592 Her is more striking than in the 2001 superoutburst of WZ Sge. A linear fit to the first 1 d of the light curve has yielded a mean decay rate of 0.98 mag d\(^{-1}\). The decay rate decreased to 0.05 mag d\(^{-1}\) during the late half of the plateau phase. The initial decay rate was 4 times larger than that of the 2001 superoutburst of WZ Sge (Cannizzo 2001).\(^7\) By applying the relation between the viscous decay time-scale (\(\tau_v\)) and the surface density in the disk (\(\Sigma\)), \(\tau_v \propto \Sigma^{-3/7}\) (Cannizzo 2001) to the initial decay rate, the initial surface density is estimated to be \(\sim 25\) times larger than that in the initial part (derived from an average of the first 15 d) of the 2001 superoutburst of WZ Sge.

WZ Sge-type dwarf novae are known to frequently (but not always) show post-outburst rebrightenings (for a review, see Kato et al. (1998). See also Richter (1992); Howell et al. (1995); Kuulkers et al. (1996); Kuulkers (2000); Kato et al. (1997); Patterson et al. (1998)].\(^8\) Due to the faintness of the object, the existence of such a post-superoutburst rebrightening was not unambiguously confirmed during the present outburst of V592 Her, although there may have been a hint of such phenomenon on October 3 (JD 2451090). However, a long-lasting rebrightening as observed in AL Com (Kato et al. 1996; Nogami et al. 1997; Patterson et al. 1996), WZ Sge in 2001 (Ishioka et al. 2002; Patterson et al. 2002), and V2176 Cyg (Novák et al. 2001) was not recorded. There was no hint of a bright rebrightening as expected by Buat-Ménard, Hameury (2002).

4.2. Superhump Period

Duerbeck, Mennickent (1998) reported the detection of superhumps (period either 0.06007 d or 0.06391 d) based on their three-night observation. A closer look at the data by Duerbeck, Mennickent (1998) left some uncertainty regarding this period determination, mainly because only one superhump per night was observed, which makes unique alias selection virtually impossible. In order to solve this problem, we have digitized the figure in Duerbeck, Mennickent (1998) and measured their observations to an accuracy of 0.001 mag and 0.0001 d. Although a period analysis of these data has confirmed the claimed periods by Duerbeck, Mennickent (1998), there remains substantial possibility around \(P = 0.0567\) d (see also the upper panel of figure 3).

We have further extracted the times of superhump maxima from our observations between 1998 September 2 and September 7 (early part of the superoutburst plateau, see figure 2). These observations covered an earlier epoch than in Duerbeck, Mennickent (1998). The times of maxima were determined by fitting the average superhump light curve (given in figure 5) to the observed data. The maximum times and 1-\(\sigma\) errors of timing estimates were determined with Marquardt-Levenberg method (Marquardt 1963). The validity of the fits has also been confirmed with a comparison of independent eye extraction of maximum times. Table 2 lists the measured timings of the superhump maxima. The values are given to 0.0001 d in order to avoid the loss of significant digits in a later analysis. These maxima are not well ex-

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\(^7\) The first 15-d average of the decline rate in V592 Her is comparable to that in WZ Sge (Cannizzo 2001). Since the effect of a viscous decay is stronger near the outburst peak, we use the initial decline rate described in the text.

\(^8\) These phenomena are sometimes referred to as echo outbursts, but we avoid 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 physically different from dwarf nova-type rebrightenings.
pressed by either of the two candidate periods listed in Duerbeck, Mennickent (1998). In particular, the interval of 0.396 d between the BJD 2451062.911 and 2451063.307 is only well expressed by a period near 0.057 d within their respective errors (this interval corresponds to 6.59 and 6.20 cycles of the two candidate periods (Duerbeck, Mennickent 1998) of 0.06007 and 0.06391 d, respectively). We thus conclude that the short alias (P \sim 0.0567 d) is the true superhump period. The cycle counts (E) in table 2 are calculated with this period. A linear regression to the observed superhump times gives the following ephemeris (the errors correspond to 1-\sigma errors at the epoch of E = 67):

\[ \text{BJD(max)} = 2451058.9005(10) + 0.056498(13)E. \] (1)

Figure 3 shows the result of period analysis of superhumps with the Phase Dispersion Minimization (PDM, Stellingwerf 1978). The upper panel shows an analysis of the data in Duerbeck, Mennickent (1998), which shows the possibility of many one-day aliases. The lower panel shows an analysis of the combined data (this work and Duerbeck, Mennickent 1998), which covered the superoutburst plateau between JD 2451057 (September 1) and 2451067 (September 11). A strong preference of the frequency of 17.716(8) \text{d}^{-1}, which corresponds to a period of \( P = 0.05645(2) \text{d} \), is clearly seen. An exclusion of the data of Duerbeck, Mennickent (1998) did not significantly change this trend. The selection of the true alias is confirmed by these analyses. The significance level of this period is above 95 \%. Figure 4 shows period analysis of

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|}
\hline
\text{BJD} & \text{Error} & \text{E} & \text{O - C1} & \text{Ref.} \\
\hline
58.9003 & 10 & 0 & -2 & 1 \\
58.9576 & 15 & 1 & 6 & 1 \\
59.8634 & 23 & 17 & 24 & 1 \\
59.9180 & 14 & 18 & 5 & 1 \\
62.9107 & 23 & 71 & -12 & 1 \\
63.3070 & 26 & 78 & -3 & 1 \\
63.8718 & 25 & 88 & -5 & 1 \\
63.9257 & 20 & 89 & -31 & 1 \\
64.4910 & 7 & 99 & -28 & 2 \\
65.5123 & 6 & 117 & 16 & 2 \\
67.4913 & 9 & 152 & 31 & 2 \\
\hline
\end{tabular}
\caption{Timings of superhumps.}
\end{table}
superhumps in V592 Her with the Clean method (Roberts et al. 1987), with a gain parameter of 0.01. The data and the frequency range are the same as in the lower panel of figure 3. The Cleaned spectrum clearly shows that the frequency of $17.72 \text{ d}^{-1}$ is the only acceptable period.

We finally adopted $P_{\text{SH}} = 0.05648(2)$ from an average of superhump timing analysis and PDM analysis.

Figure 5 shows a mean superhump profile phase-folded with a period of $P_{\text{SH}} = 0.05648 \text{ d}$. The rapid rising and slowly declining profile is characteristic to SU UMa-type superhumps (Vogt 1980, Warner 1985). The mean amplitude (0.15 mag) of superhumps is smaller than those of usual SU UMa-type dwarf novae, but is close to that of a WZ Sge-type star, HV Vir (Kato et al. 2001b).

The newly established superhump period ($P_{\text{SH}} = 0.05648(2) \text{ d}$) is extremely close to those of WZ Sge ($P_{\text{SH}} = 0.05726(1) \text{ d}$: Ishioka et al. 2002, Patterson et al. 2002), AL Com ($P_{\text{SH}} = 0.05722(1) \text{ d}$: Kato et al. 1996, Patterson et al. 1996), the two best-studied WZ Sge-type dwarf novae. All known WZ Sge-type dwarf novae have $P_{\text{SH}}$ shorter than 0.060 d except RZ Leo and EG Cnc (see e.g. Kato et al. 2001b). Among them, the long period of RZ
Leo is compatible with the evidence of a relatively massive secondary (Ishioka et al. 2001). Since the secondary of V592 Her is apparently less luminous (van Teeseling et al. 1999) than in RZ Leo, the new period better fits the general WZ Sge-type characteristics without necessarily introducing, as we will see, a possibility of a brown dwarf secondary.

4.3. Superhump Period Change

In contrast to the “textbook” decrease of the superhump periods in usual SU UMa-type dwarf novae (e.g. Warner 1985; Patterson et al. 1993), WZ Sge-type dwarf novae are recently known to show virtually zero or even increase of the superhump periods (for a summary, see Kato et al. 2001b). The quadratic term determined from the superhump maximum timings corresponds to \( \dot{P} = +1.2 \pm 0.4 \times 10^{-6} \text{ cycle}^{-1} \) or \( \dot{P}/P = +2.1(0.8) \times 10^{-5} \). This value indicates a small, but significant, period increase in V592 Her (figure 6). This rate is comparable to the period changes observed in WZ Sge (Ishioka et al. 2002; Patterson et al. 2002).

4.4. Early Superhumps and Orbital Period

All well-observed WZ Sge-type dwarf novae are known to show double-humped modulations having a period very close to the system orbital period during the earliest stage of superoutbursts (Kato et al. 1996; Matsumoto et al. 1998; Patterson et al. 1996; Nogami et al. 1997; Ishioka et al. 2001; Kato et al. 2001b; Ishioka et al. 2002; Patterson et al. 2002). These modulations are called early superhumps.\(^9\) The presence of early superhumps is the unique characteristic of WZ Sge-type dwarf novae (Kato et al. 2001a). Although the origin of early superhumps is controversial, several interpretations have been historically proposed: (1) enhanced hot spot caused by a sud-

\(^9\) This feature is also referred to as orbital superhumps (Kato et al. 1996), outburst orbital hump (Patterson et al. 1998) or early humps (Osaki, Meyer 2002).

\(^{10}\) Due to the shortness of each runs, any trial period between 0.05592 d (adopted \( P_{\text{orb}} \)) and 0.05648 d (\( P_{\text{SH}} \)) gives the virtually same waveform. Strictly speaking, we cannot distinguish early superhumps from (the growing stage of) superhumps from these observation only. However, we consider it likely that these modulations reflect early superhumps because the transition from early superhumps to superhumps has been to confirmed to occur less than 1 d in WZ Sge (Ishioka et al. 2002; Patterson et al. 2002). A chance to observe the growing stage of superhumps on two nights is expected to be very small.

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same time-evolution as in superoutbursts of ordinary SU UMa-type dwarf novae (Osaki 1995).

The peak magnitudes of these ordinary outbursts are limited by the critical surface density ($\Sigma_{\text{max}}$) required by the disk instability theory (Cannizzo 1998). The calculated peak magnitudes are known to well reproduce the Warner’s relation. Cannizzo (1998) originally restricted the discussion to SS Cyg-type dwarf novae, but the same discussion can be naturally extended to the upper limits of $M_V(\text{max})$ of normal outbursts of SU UMa-type dwarf novae. Superoutbursts are generally $\sim 0.5$ mag brighter than upper-limit magnitudes of normal outbursts (Warner 1995b), caused by an extra heating by tidal dissipation, a safe upper limit of $M_V(\text{max})$ for ordinary SU UMa-type superoutbursts is estimated to be 0.5 mag brighter than the extrapolation of Cannizzo (1998). In the case of V592 Her, this value corresponds to $M_V(\text{max}) \sim +4.8$, which is consistent with the reported $M_V(\text{max}) \sim 3.8–5.3$ for observed superoutbursts (Warner 1995a).

We should hence compare the expected $M_V(\text{max})$ not with the observed peak magnitude, but with the magnitude at which the viscous decay finishes, in other words, an ordinary plateau phase begins. As can be seen in figure 1 and a comparison with a simulation in (Osaki 1995), V592 Her experienced this phase change at $V = 14.0$ (considering that CCD observations tended to give slightly fainter magnitudes than visual observations, and considering the difficulty in accurately estimating such a faint magnitude visually, this magnitude would better be regarded as an upper limit of the plateau phase). While van Teeseling et al. (1999) estimate a distance $d \sim 220–440$ pc using a peak magnitude of $V = 12$, our estimation hence provides larger distances of $d \geq 550–1100$ pc.

Another caveat in van Teeseling et al. (1999) is that they used a wrong (longer) superhump period based on Duerbeck, Mennickent (1998). By adopting the correct $P_{\text{SH}} = 0.05648(2)$ and estimated $P_{\text{orb}} = 0.05592(3)$ d, the expected absolute magnitude of a main-sequence secondary filling the Roche-lobe of this $P_{\text{orb}}$, is at least $\sim 1.0$ mag fainter (Baraffe et al. 1998). Based on the same method of estimate in van Teeseling et al. (1999), the lower limit of the distance from a comparison of apparent magnitudes and the absolute magnitude of a main-sequence secondary is now lowered to 900 pc or even lower. This lower limit of the distance is now not at all inconsistent with an estimate from the outburst photometry.

The present new determinations of the true $P_{\text{SH}}, P_{\text{orb}}$ and the new distance estimate are thus consistent with a lower main-sequence secondary. By considering a main-sequence secondary with $M_I = 12.4$ (which corresponds to an upper limit of the luminosity of a main sequence filling the Roche-lobe of V592 Her), the observed color $R - I \sim 0.2$ can be naturally explained by a contribution of this secondary star. In this case, we don’t need to assume an extremely cold ($\sim 10000$ K) white dwarf as deduced in van Teeseling et al. (1999). Although accurate determination of the white dwarf temperature should await optical-UV spectroscopy, this finding seems to be consistent with recent determinations of white dwarf temperatures in WZ
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Sge-type dwarf novae (EG Cnc: 11700–13000 K, HV Vir: 12500–14000 K Szkody et al. 2002b; GW Lib: 14700 K in average Szkody et al. 2002a; LL And: 15000 K Howell et al. 2002). The present conclusion is also comparable to recent result in WZ Sge itself (Steeleghs et al. 2001a), who concluded that a lower main-sequence secondary is still viable in spite of all the past negative efforts in directly detecting a signature of emission from the secondary of WZ Sge. In conjunction with the present conclusion, the presence of a brown dwarf in WZ Sge-type dwarf nova is still an open question even in most promising cases.11

4.6. Related Objects

As stressed in Kato et al. (2001b), light curves of some WZ Sge-type dwarf novae often display similar characteristics to those of very fast novae. The present, first-ever fully obtained, light curve of V592 Her (figure 1) marks an even stronger similarity. In WZ Sge itself, either a lower surface density at the beginning of an outburst, or a self-shielding effect arising from a nearby edge-on view, may have reduced this effect. In this context, the present light curve of V592 Her even “better” reproduce the expected light curve of a WZ Sge-type dwarf nova (Osaki 1995). As seen in subsection 4.4, this light curve may be a result of a low binary inclination in V592 Her. Among the stars listed in Kato et al. (2001b), V358 Lyr (Richter 1986), LS And (Sharov, Karinova 1978) and V4338 Sgr have very similar light curves to that of V592 Her. These objects may comprise a group of WZ Sge-type dwarf novae which is either characterized by a stronger effect of initial viscous decay, or a lower binary inclination. None of these systems, including V592 Her (van Teeseling et al. 1999), have been detected in ROSAT surveys (Verbunt et al. 1997; Voges et al. 1999). Apparently low X-ray luminosities of these systems makes a striking difference from the relatively strong quiescent X-ray detection in WZ Sge (Verbunt et al. 1997). This difference from WZ Sge may be a result of an even smaller quiescent viscosity, which could explain a stronger effect of initial viscous decay.

5. Summary

We observed the entire course of the 1998 outburst of V592 Her, which was originally reported as a nova in 1968. We have been able to first time construct a full light curve of the outburst, which is characterized by a rapid initial decline (0.98 mag d⁻¹), which smoothly developed into a plateau phase with a slower linear decline. The initial rapid decay has been interpreted as a result of viscous decay theoretically and naturally expected for a high surface-density accretion disk in a WZ Sge-type outburst. We detected superhumps characteristic to SU UMa-type dwarf novae ~7 d after the optical maximum. The overall behavior of the light curve and the development of superhumps were characteristic to a WZ Sge-type dwarf nova, although there was little evidence of early superhumps, which may have been either escaped from detection because of the unfavorable observational coverage or because of a low orbital inclination. We examined astrometry of V592 Her using modern material, and have yielded a safe upper limit (0.06 yr⁻¹) of its proper motion. The result in van Teeseling et al. (1999) would have been somehow overestimated. Combined with the past literature, we have been able to uniquely determine the superhump period to be 0.05648(2) d. We detected a small, but significant, positive period change (ΔP/P = +2.1(0.8) × 10⁻⁵) of superhumps. We estimated an expected orbital period of 0.05592(3) d. From these periods, together with the modern interpretation of the absolute magnitude of the outburst light curve, we conclude that the overall picture of V592 Her is not inconsistent with a lower main-sequence secondary star in contrast to a previous claim that V592 Her contains a brown dwarf.

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Ciardi, D. R., Howell, S. B., Hauschildt, P. H., & Allard, F. 11 Mennickent et al. (2002) concluded, from their identification of \( P_{rb} \), that \( \epsilon \) supports the brown-dwarf like nature of the secondary star. However, as discussed in subsection 4.4, the correct \( P_{rb} \), is their \( P_1 = 0.0561(4) \) d. This value gives \( \epsilon = 0.7 \pm 0.7\% \), which essentially gives no constraints on the existence of a brown dwarf. Furthermore, velocity fields of emission lines in WZ Sge-type superoutbursts are known to be very complex (Baba et al. 2002), or even systematically vary (Kato 2002). Radial velocity variation of emission lines in WZ Sge-type superoutbursts thus may not reasonably trace the binary motion as a priori assumed in Mennickent et al. (2002).
