The Peculiar 2004 Superoutburst in the Helium Dwarf Nova, 2003aw

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Abstract

We conducted a time-resolved photometric campaign of the helium dwarf nova, 2003aw in 2004 May–June. 2003aw stayed at 14.7–15.7 mag for the first several days during this campaign, which is the plateau phase of this superoutburst. This variable then rapidly decayed to ~18.0 mag, still brighter by about 2 mag than its quiescence magnitude, and maintained this brightness for about 20 days, having short flares of ~2 mag. A long fading tail followed it. We detected superhumps with a period of 0.02357(4) d [= 2036(3) s] during the plateau phase. The whole light curve of the superoutburst in 2003aw, taking into account the present data and those in the literature, perfectly resembles that of the 1996-1997 superoutburst of the peculiar WZ Sge-type hydrogen-rich dwarf nova, EG Cnc.

Key words: accretion, accretion disks — stars: dwarf novae — stars: individual (SN 2003aw) — stars: novae, cataclysmic variables — stars: oscillations

1. Introduction

Interacting binaries consisting of two white dwarfs (IBWDs) are called AM CVn stars (Solheim 1995; Warner 1995a). Helium gas transferred from the less massive white dwarf forms an accretion disk around the primary. There are 11 confirmed members including 2003aw in this class, 10 of which (and 2 candidates) are listed in table 1 in Woudt, Warner (2003), and SDSS J1240–01 is the most recently discovered (Roelofs et al. 2004). They have three activity groups, mainly depending on the mass-transfer rate $\dot{M}$, like hydrogen-rich cataclysmic variables (CVs; for a review, Warner 1995b). They are, from the high-$\dot{M}$ systems, 1) stable systems with a hot accretion disk, corresponding to nova-likes in CVs, 2) systems having outbursts, corresponding to dwarf novae, 3) stable systems with a cold disk. 2003aw is the 6th member of the helium dwarf novae.

This star was discovered as a supernova (therefore named 2003aw) by Wood-Vasey et al. (2003) from the unfiltered NEAT image taken with the Palomar 1.2m Schmidt telescope. The magnitude at the discovery on 2003 February 6 was 17.8, and this ‘supernova’ was seen also in the images taken on 2003 February 10 and 19. Chornock, Fillipenko (2003) obtained an optical spectrum, which had a quite blue continuum with weak He i emission lines and Ca ii H and K absorption at nearly zero redshift. They commented that 2003aw is not a supernova, but rather is a hydrogen-deficient dwarf nova similar to that proposed for 1998di = KL Dra (see Jha et al. 1998).

Woudt, Warner (2003) carried out intensive high-speed photometry of 2003aw in an active phase between 2003 February 28 and June 9. They divided their observations into three states. In the high state, 2003aw was in $V = 17.6 \pm 0.5$ and at around $V = 20.3$, respectively. Several curious features were revealed by them, such as superhumps with a period of 2041.5 ±0.3 s, brightness cycles over 0.4 mag, and a flare reaching $V = 19.0$. In the intermediate state and quiescence, 2003aw was at about $V = 19.6$ and at around $V = 20.3$, respectively. Several curious features were revealed by them, such as superhumps with a period of 2041.5 ±0.3 s, brightness cycles over 0.4 mag, and a flare reaching $V = 19.0$.

2. Observation

The observations were carried out at four sites, Tiegerpoort in South Africa (BM), Exmouth in Australia (AL), Concepcion in Chile (MU), and Kyoto in Japan (RI, AM, and TK). Table 1 summarizes the log of the obser-
Table 1. Log of observations.

| Date  | HJD-2453000 | Exposure Time (s) | Useful Frames | Mean Mag. | Comparison Site | Sky Condition |
|-------|-------------|-------------------|---------------|-----------|----------------|---------------|
| 2004 May 18 | 143.960–144.058 | 60 | 86 | 15.7(0.1) | 1 | A |
| 144.005–144.019 | 30 | 35 | 15.2(0.8) | 1 | B | thin clouds |
| 144.173–144.329 | 28 | 440 | 15.2(0.1) | 1 | C |
| 19 145.179–145.304 | 28 | 353 | 15.3(0.1) | 1 | C |
| 20 145.953–146.060 | 60 | 93 | 14.7(0.1) | 1 | A |
| 146.182–146.287 | 28 | 202 | 15.7(0.1) | 1 | C |
| 22 147.956–148.057 | 60 | 90 | 16.6(0.2) | 1 | A |
| 24 149.974–149.979 | 30 | 4 | 16.1(0.7) | 1 | B | thin clouds |
| 25 150.960–151.057 | 60 | 61 | 17.6(0.3) | 1 | A |
| 26 152.169–152.260 | 28 | 254 | 16.4(0.2) | 1 | C |
| 27 152.975–153.051 | 90 | 50 | 18.3(0.3) | 2 | A |
| 28 153.959–154.068 | 90 | 72 | 18.1(0.3) | 2 | A |
| 29 154.953–155.057 | 90 | 66 | 18.1(0.3) | 2 | A |
| June 6 162.447–162.454 | 30 | 8 | 18.6(0.9) | 1 | D |
| 6 163.457–163.463 | 30 | 9 | 18.1(0.6) | 1 | D |
| 9 166.181–166.203 | 28 | 59 | 16.1(0.1) | 1 | C |
| 166.432–166.536 | 30 | 81 | 17.0(0.6) | 1 | D | thin clouds |
| 12 169.445–169.506 | 30 | 24 | 17.5(0.7) | 1 | D | thin clouds |
| 29 186.442–186.447 | 30 | 3 | 18.0(0.9) | 1 | D | thin clouds |

1: 2UCAC 29829807, 11.3 mag, 2: 2UCAC 29829819, 16.1 mag  
†: A: 30cm Tel. + SBIG ST-7E (Exmouth, Australia), B: 30cm Tel. + SBIG ST-7E (Kyoto, Japan), C: 32cm Tel. + SBIG ST-7E (Tiegerpoort, South Africa), D: 30cm Tel. + Pictor 416XT (Concepcion, Chile)

The differential magnitudes of 2003aw were measured, assuming the unfiltered CCD magnitudes of the nearby comparison stars, 2UCAC 29829807 and 2UCAC 29829819, to be 11.3 and 16.1, respectively, based on the UCAC2 magnitude (see Zacharias et al. 2004 regarding UCAC2). The UCAC bandpass is 579–642 nm, between $V$ and $R_c$. The error in the comparison magnitude is expected to be within 0.5 mag.

Heliocentric corrections to the observation times were applied before the following analysis.

3. Results

The long-term light curve is drawn in figure 1. At the first stage of our campaign, 2003aw was recorded to be at 15.1–15.7 mag with a brightening to 14.7 mag on May 20. Even considering the zero-point uncertainty of the magnitude and the color, this maximum magnitude far exceeds the brightest magnitude at a brightening ($V = 16.5$) in the ‘high’ state during the 2003 February/March outburst (Woudt, Warner 2003). The detection of the superhumps (described later) indicates that this phase corresponds to the plateau phase of the superoutburst in AM CVn stars and SU UMa-type dwarf novae. It is unclear how long the plateau phase lasted before our observations started.

After the decline from the plateau phase, 2003aw kept its brightness around 18.0 mag, besides occasional flares reaching $\sim 15.8$ mag, for $\sim 20$ days. During this phase, 2003aw was still brighter by about 2.0 mag than in quiescence.
escence, which corresponds to the high state in Woudt, Warner (2003). Judging from our observations and those reported to VSNET (see figure 1), the duration of the flares is 1 day, or so, but a periodicity of the flare cannot be supported nor rejected from the available sparse data. This behavior is completely consistent with that during the high state in the 2003 February/March active phase (Woudt, Warner 2003).

A gradual fading to quiescence [the intermediate state defined by Woudt, Warner (2003)] followed the high state. We could not, however, continue the observations well during and after this state with our 30cm telescopes.

Figure 2 shows the enlarged light curves of each long run during the plateau phase. There exist modulations with variable shapes, amplitudes, and timescales. Those shown in figures 2a have a large amplitude up to 0.5 mag and an unstable timescale. We see small, stable modulations in figures 2b and 2c, which are interpreted as superhumps. A rapid brightening with a rate of 4.4 mag d$^{-1}$ is displayed in figure 2d, but 2003aw decayed by 0.9 mag during the following 3 hours by the start of the run of figure 2e.

We performed period analyses by the Phase Dispersion Minimization (PDM) method (Stellingwerf 1978) and the Fourier transformation for all the data in figures 2b and 2c containing the stable superhumps. Before these analyses, a pre-whitening removing variations with timescales longer than hours was processed. The resultant Θ diagram and power spectrum are exhibited in figure 3. The best estimated superhump period is 0.02357 (±0.00004) d [= 2036 (±3) s]. The error of the period was estimated using the Lafler-Kinman class of methods, as applied by Fernie (1989). This period is different by ∼2 σ from the value [2041.5 (±0.3) s] derived by Woudt, Warner (2003). This difference can not be considered statistically significant, though a similar difference in the superhump period in the different outburst states were observed in another AM CVn star, V803 Cen (Kato et al. 2004b). Including the data shown in figures 2a and 2d did not improve the period determination.

We could not detect firm evidence of any sidebands, which would be (at least partly) due to short coverages and low signal-to-noise ratios of our data.

The averaged superhump profiles are exhibited in figure 4. There is a hint of a dip after the superhump maximum on 2004 May 18 (figure 4a). The same phenomenon was observed by Woudt, Warner (2003) during the high state. On this day, the superhumps had a shape consisting of a rapid rise and a slow decline, which is typically seen in hydrogen-rich SU UMa-type dwarf novae. On the next day, 2004 May 19, the superhump had evolved into a symmetric shape (figure 4b).

The timings of the superhump maxima were extracted...
the high state for ∼a rate over 1 mag d
phase. Following this phase, the star sharply decayed with
ence of superhumps with a period of 2036(3) s during this
by fitting the average superhump light curve in figure 4,
and we tried to check the change of the superhump period
during these states in both stars.

The whole outburst light curve of 2003aw, taking into account the observations by us and Woudt, Warner (2003), has strong resemblance to the superoutburst of the peculiar WZ Sge-type dwarf nova, EG Cnc, in 1996–1997 (Patterson et al. 1998; Kato et al. 2004a), in terms of the first quite bright state (the plateau phase in 1996–1997 (Patterson et al. 1998; Kato et al. 2004a), the following repetitive-outburst state still brighter than the quiescence (the high state in 2003aw, and the rebrightening phase in EG Cnc), and the long fading tail to the quiescence (the intermediate state in 2003aw, and the long fading tail in EG Cnc). Superhumps were observed throughout these states in both stars.

The thermal-tidal disk-instability models for the AM CVn stars have been developed by Smak (1983), Cannizzo (1984), and Tsugawa, Osaki (1997). To explain the peculiar outburst behavior in EG Cnc, a modification of the disk-instability model for hydrogen-rich dwarf novae was introduced by Osaki et al. (2001), adding an idea of the viscosity decay in the cold disk. A similar idea may be necessary in reconstructing the full outburst property of 2003aw, although we need further observations to clarify the total outburst pattern including that outside the superoutbursts1. The repetition of the large flares after the plateau phase will be a key also in trying to consider the behavior of 2003aw with the models making use of the variation in the mass-transfer rate (Warner 1995c), or the effect of the magnetic fields on the primary white dwarf (Woudt, Warner 2003).

The repetitive-outburst (high) state casts another problem concerning a notable difference in the superoutburst between 2003aw and EG Cnc. In 2003aw, small brightness variations with an amplitude of ∼0.4 mag and a period of ∼16 h were observed, other than a large flare of 1.9 mag by Woudt, Warner (2003), while corresponding modulations were not reported in EG Cnc (Patterson et al. 1998; Kato et al. 2004a). The resemblance of the outburst-light curves between an AM CVn star and a WZ Sge star was first pointed out by Kato et al. (2004b) concerning V803 Cen and WZ Sge. After the initial, long outburst stage, V803 Cen showed ∼1 mag oscillations with periods of 0.8–1.0 d, which resembles the rebrightening stage of the 2001 superoutburst in WZ Sge. Kato et al. (2004b) attributed those oscillations to some sort of thermal disk-instability, instead of the full-disk outbursts. To fully understand the outburst mechanism in 2003aw, we must explain the 0.4-mag oscillations with a timescale of 16 h and the occasional flares up to 2 mag.

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1 Note that the outburst pattern in AM CVn stars can vary in a timescale of years (Patterson et al. 2000; Kato et al. 2001; Kato et al. 2004b).

Fig. 4. The superhump profile folded with the superhump period derived in this work and averaged. Panels (a) and (b) use the data shown in figures 2(b) and 2(c), respectively. There is a hint of a dip around phase 0.1 in (a) superposed on a typical superhump shape with a rapid rise and a slow decay. During the following ∼40 superhump cycles, the superhump shape became rather symmetric.
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