Photometry of the dwarf nova AW Sagittae during the 2006 November superoutburst

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During 2006 November an outburst of the dwarf nova AW Sge was observed using CCD photometry. This revealed 0.25 magnitude superhumps confirming it to be a superoutburst, possibly only the second confirmed such outburst of this star. The superhumps were observed for 4 days and had a stable period P_{sh} = 0.0745(2)d, a value which is consistent with P_{sh} measured during the 2000 superoutburst.

Introduction

Dwarf novae are a class of cataclysmic variable star in which a white dwarf primary accretes material from a secondary star via Roche lobe overflow. The secondary is usually a late-type main-sequence star. In the absence of a significant white dwarf magnetic field, material from the secondary is processed through an accretion disc before settling on the surface of the white dwarf. As material builds up in the disc, a thermal instability is triggered that drives the disc into a hotter, brighter state causing an outburst in which the star brightens by several magnitudes.[1] Dwarf novae of the SU UMa family occasionally exhibit superoutbursts which last several times longer than normal outbursts and may be up to a magnitude brighter. During a superoutburst the lightcurve of a SU UMa star is characterised by superhumps. These are modulations in the lightcurve which are a few percent longer than the orbital period. They are thought to arise from the interaction of the secondary star orbit with a slowly precessing eccentric accretion disc. The eccentricity of the disc arises because a 3:1 resonance occurs between the secondary star orbit and the motion of matter in the outer accretion disc. For a more detailed review of SU UMa stars and superhumps, the reader is directed to references 2 and 3.

History of AW Sge

AW Sge was first reported variable by M. & G. Wolf during their photographic search for variable stars in the vicinity of γ Sge conducted in the opening years of the twentieth century.[4] They detected it on two occasions, in 1901 and 1905, at magnitude 13 and 15 respectively, whereas on a further five occasions between 1900 and late 1905 it was not visible. The star was subsequently included in Vogt and Bateson's atlas of possible dwarf novae by virtue of its blue colour.[5]

Table 1. Recent reported outbursts of AW Sge

Date (UT)	*Magnitude at discovery*	*Observer*
1996 Sep 17.900	15.0C	J. Pietz[6]
2000 Jul 11.565	14.0v	R. Stubbings[7]
2002 Oct 31.036	14.4v	M. Simonsen
2004 May 22.444	14.8CR	P. Schmeer
2006 Nov 16.764	14.8C	J. Shears

Unless specified otherwise, data are from the AAVSO International Database. C= unfiltered CCD; CR = unfiltered CCD, calibrated with R (red) comparison star sequence; v= visual

The first confirmed outburst of AW Sge in modern times was detected by J. Pietz in 1996[6] and to date a total of five outbursts have been reported, including the one discussed in this paper (Table 1). The shortest time between outbursts is 569 days and the longest is 1393 days, with a median outburst interval of 890 days. However, it is entirely possible that other outbursts have been missed.

To investigate this further, we examined the American Association of Variable Star Observers (AAVSO) International Database, which contains almost five thousand observations of AW Sge since 1981 August, for other outbursts. This was not straightforward as we found that several observers always recorded AW Sge as impossibly bright

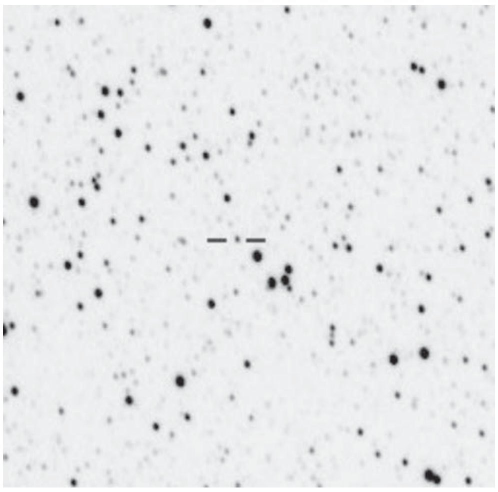

Figure 1. AW Sge in outburst at 14.8C on 2006 Nov 16.764. 8'×8' with south at top. *(Jeremy Shears)*

Table 2. Instrumentation used

Observer	*Instrumentation*
JS	0.1m fluorite refractor + Starlight Xpress SXV-M7 CCD
TK	0.28m SCT + SBIG ST-7E CCD
RP	0.30m SCT+ Starlight Xpress MX716 CCD + V filter

at times when other observers reported no outburst: some had it routinely ~12th magnitude and some at ~14.8–15.1. We suspect that another star has been mistaken for the variable in what is a rich field. Hence we decided to omit observations by these observers, especially as there was no independent confirmation by others. The remaining observations were either negative observations (mainly visual), or very faint CCD measurements of the star at quiescence (mag 18 to 19). Thus we can find no evidence of outbursts other than those in Table 1. However, seasonal gaps of 2 to 3 months are common in the observational record presumably due to the field being poorly located near the Sun or else inconveniently located in the pre-dawn sky, a time when fewer observers are active.

Photometry by Henden in 1999 June showed AW Sge at 19.3V, which we take as its magnitude at quiescence.[8] Based on the brightness of the 2000 outburst at discovery, this suggests an outburst amplitude of at least 5.3 magnitudes.

Time resolved photometry by G. Masi & M. A. Tosti during the 2000 outburst revealed the presence of superhumps, confirming that this was a superoutburst and thus identifying AW Sge as a member of the SU UMa family.[9] The superhump period, P_{sh}, was quoted as 0.0745d in a paper by Kato *et al.* which cites Masi as the source.[3] During this outburst AW Sge's position was determined by Masi as RA 19h 58m 37.11s, Dec +16° 41' 28.8" (J2000).

According to observations in the AAVSO International Database, the 2000 superoutburst lasted at least 8 days. By contrast, the outbursts in 1996, 2002 and 2004 lasted 4 days or less and are therefore more likely to have been normal outbursts. We note that ~4 % of observations in the AAVSO International Database were separated by more than four days, so again outbursts could have been missed.

In an attempt to encourage monitoring of the star for outbursts, AW Sge was added to the BAA Variable Star Section's (VSS) Recurrent Objects Programme in 1994.[10] This programme was set up as a joint project between the VSS

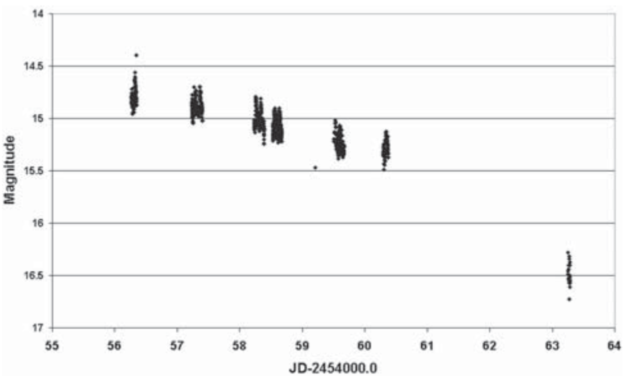

Figure 2. Lightcurve of the 2006 November outburst. Unfiltered or V (Visual) filtered CCD measurements; data is from the authors, plus the AAVSO International Database.

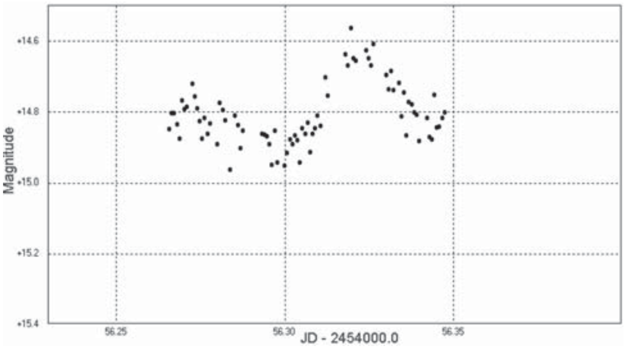

Figure 3. Time-series data from 2006 Nov 16 *(J. Shears).*

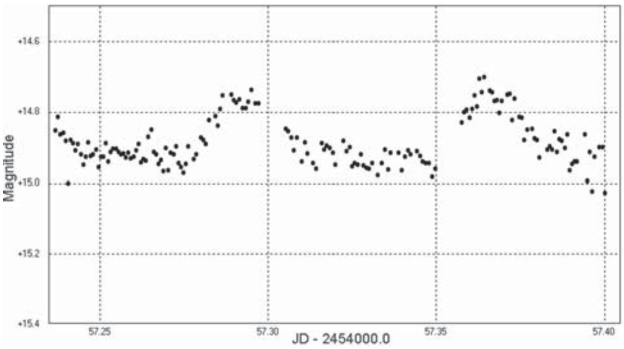

Figure 4. Time-series data from 2006 Nov 17 *(R. Pickard).*

and *The Astronomer* magazine specifically to monitor poorly studied eruptive stars of various types where outbursts occur at intervals of greater than 1 year. Observing charts and sequences for AW Sge are available from the AAVSO.[11]

Detection and course of the outburst

The outburst reported here was first detected by JS on 2006 Nov 16.764 at 14.8C,[12] rising to 14.6C by Nov 16.819 (Figure 1) and was independently detected later the same night by GP on Nov 16.846 at 14.4v.[13] This was significantly fainter than the 2000 outburst, which could indicate that the outburst was already well advanced and beginning to decline, however the AAVSO International Database records a negative observation by Eddie Muyllaert at <14.0v on Nov 15.796, only ~24 hours before the outburst was detected.

Figure 2 shows the overall light curve of the outburst covering the 8 days for which positive observations exist. During the first 4 days following detection, the star faded at

Table 3. Log of time-series observations

Run no.	*Date (2006)*	*Start time (JD–2454000)*	*Duration (hrs)*	*No. of images*	*Mean mag.(C)*	*Obs.*
1	Nov 16	56.267	1.9	79	14.81	JS
2	Nov 17	57.237	3.8	167	14.88	RP
3	Nov 18	58.230	3.4	153	15.01	RP
4	Nov 19	58.531	3.4	326	15.06	TK
5	Nov 20	59.537	3.1	214	15.25	TK
6	Nov 20	60.291	1.9	81	15.28	RP

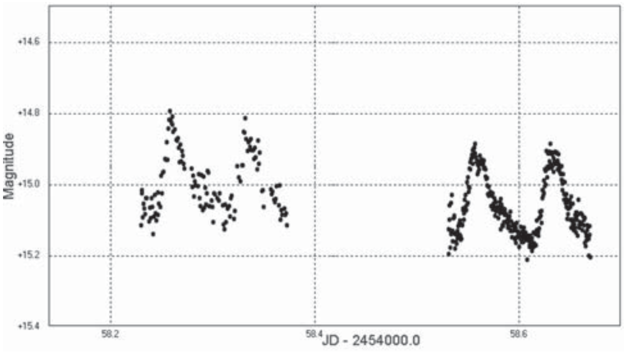

Figure 5. Time-series data from 2006 Nov 18 and 19 *(R. Pickard & T. Krajci).*

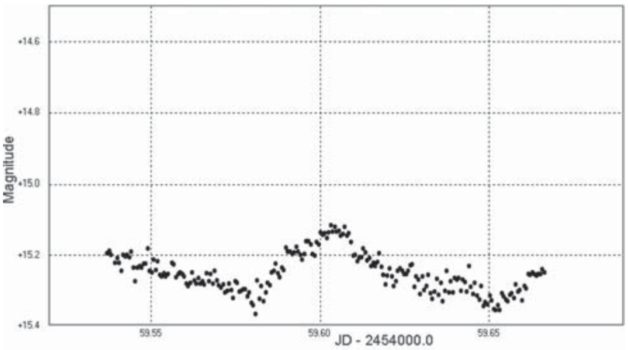

Figure 6. Time-series data from 2006 Nov 20 *(T. Krajci).*

an average rate of 0.12 mag/d. This is typical of a dwarf nova in the initial stages of decline. There then followed a more rapid decline at 0.38 mag/d, which is again typical of the final stages of a dwarf nova outburst.

Detection of superhumps

Six time-series photometry runs were conducted during the outburst yielding more than one thousand individual CCD images and totalling 17.5 hours of data. Table 2 summarises the instrumentation used and Table 3 contains a log of the time-series runs. In all cases raw images were flat-fielded and dark-subtracted, before being analysed using commercially available photometry software: JS and RP employed *AIP4WIN* version 1[14] with GSC1616-0855 (13.223V) as the comparison star, whereas TK employed *AIP4WIN* version 2[15] with a comparison star ensemble of GSC1616-0277 and 1616-0687 (mag 11.977V and 12.095V). Unfortunately each run was necessarily rather short due to the unfavourable position of the object in the November evening sky.

The first time-series photometry data obtained on Nov 16 (Figure 3) shows a 0.25 mag hump-like feature in the lightcurve. However, the run was curtailed due to the field being obscured by local obstructions and it was not long enough to definitively characterise this feature as a superhump. Nevertheless, 0.25 to 0.3 mag superhumps were detected with certainty on Nov 17, 18, and 19; by Nov 20 they were slightly smaller, having an amplitude of 0.2 mag (Figures 4 to 6).

The detection of superhumps confirms that this was a superoutburst, the first seen since 2000 July. The two

Table 4. Timing of superhump maxima

Superhump cycle no.	*Time of maximum (JD) 2454000+*	*O–C (cycles)*
0	56.3236	−0.0067
13	57.2926	+0.0013
14	57.3671	−0.0242
26	58.2611	−0.0027
27	58.3356	−0.0107
30	58.5591	+0.0134
31	58.6336	−0.0080
44	59.6021	+0.0282
54	60.3471	−0.0295

superoutbursts were separated by more than 2300 days, however, as discussed above, it is entirely possible that other superoutbursts have been missed.

Measurement of the superhump period

In order to study the superhump behaviour, we first extracted the times of each resolvable superhump maximum from the individual light curves according to the Kwee & van Woerden method[16] using the *Peranso* software.[17] Times of 9 superhump maxima were found and these were then used to assign superhump cycle numbers which best fitted the assumption of a constant superhump period. We found that the maxima fitted well a constant superhump period P_{sh} = 0.0745(2)d, with a superhump maximum ephemeris JD 2454056.3241 + 0.0745(2) *E. The superhump cycle number, the measured times of superhump maximum and the O-C (Observed–Calculated) residuals relative to the above superhump maximum ephemeris are listed in Table 4 and a plot of residuals versus superhump cycle number is shown in Figure 7.

To confirm our measurement of P_{sh}, we carried out a period analysis of all the data from the six time series runs using the ANOVA (Analysis of Variance) algorithm in *Peranso*, after subtracting the mean and linear trend from each of the lightcurves. This gave the power spectrum in Figure 8 which has its highest peak at a period of 0.0744(4)d, consistent with our earlier finding. The superhump period error estimate is derived using the Schwarzenberg–Czerny

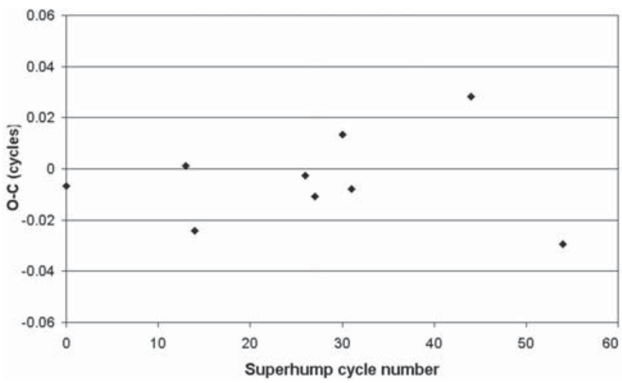

Figure 7. Plot of times of (O–C) residuals versus cycle number.

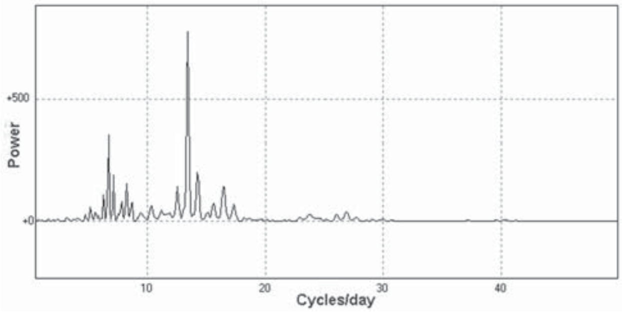

Figure 8. Power spectrum of combined time-series data.

method.[18] Removing P_{sh} from the power spectrum leaves only weak signals, none of which have any significant relationship to the superhump or orbital periods. A phase diagram of the data folded on this period is shown in Figure 9 which shows that the superhumps from each separate observing run become superimposed on each other. Hence this result also supports the assertion that the P_{sh} remained remarkably stable during the 4 days over which the outburst was followed. However, our observations cover only the first part of the superoutburst, up to the point where a more rapid fade begins; in some SU UMa stars, period changes only occur late in the outburst.[2]

We note that a superhump period of 0.0745(2)d (107.3 min) is consistent with the value reported by Kato *et al*[9] based on observations made by Masi & Tosti during the only other known superoutburst, that in 2000.

Stolz & Schoembs developed an empirical relationship between the orbital period P_{orb} and the superhump period excess $\varepsilon = (P_{sh} - P_{orb}) / P_{orb}$ in dwarf novae.[19] Using their equation (6) and our value of P_{sh} of 0.0745(2)d, it is possible to estimate that $\varepsilon \sim 0.030(8)$ and therefore P_{orb} ~0.0723(7)d. However, radial velocity measurements or photometry at quiescence are required to measure P_{orb} accurately.

Future observations

As discussed above, it is possible that outbursts of AW Sge have been missed because the normal outbursts are rather short (4 days or less) and because seasonal gaps of 2 to 3 months exist in the observational record. Hence, we encourage observers, whether visual or CCD-equipped, to monitor AW Sge for future outbursts which will help determine the true outburst frequency and the length of its supercycle. Observations at the beginning and the end of each observing season would be particularly valuable to minimise the effect of seasonal gaps.

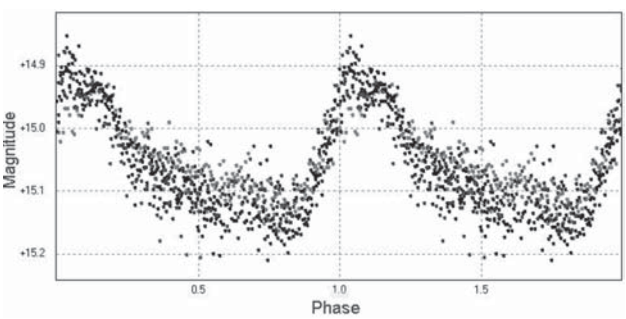

Figure 9. Phase diagram of the time-series data from runs 1 to 6.

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Note added in proof:
Dr Chris Lloyd has recently presented a more detailed analysis on the outburst history of AW Sge in the *Open European Journal on Variable Stars*, **http://var.astro.cz/oejv/issues/oejv0069.pdf**

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