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Photometric observations and numerical modeling of AW Sge

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HIGHLIGHTS

- Light curves of AW Sge at superoutburst in 2013 are presented.
- Observed positive superhump period compares well with values found by others.
- Numerically simulated positive superhump shapes to/at superoutburst are presented.
- Numerically simulated positive superhump period is within 3.5% of observed value.
- Simulation suggests retrograde precession may occur before next AW Sge outburst.

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ABSTRACT

In this work, we present *R*-band photometric light curves of Cataclysmic Variable AW Sge, an SU Uma type, near superoutburst maximum. The positive superhump shape changes over three days, from single peaked on October 11, 2013 to one maximum near phase $\phi \sim 0.3$ followed by minor peaks near phases $\phi \sim 0.6$ and $\phi \sim 0.9$, respectively, on October 13, 2013. Using the maxima from October 11–13, 2013 (JD 2456577–2356579), the observed positive superhump period is 0.074293 ± 0.000025 days.

In addition to the observations, we also provide a three dimensional Smoothed Particle Hydrodynamic simulation near superoutburst maximum, for comparison, assuming a secondary-to-primary mass ratio $q = M_2/M_1 = 0.6\,M_\odot/0.132\,M_\odot = 0.22$. The simulation produces positive superhump shapes that are similar to the observations. The simulated positive superhump has a period of 0.076923 days, which is approximately 6% longer than the orbital period, assuming an orbital period $P_{orb} = 0.0724$ days. The 3.5% difference from the observed positive superhump period is likely due to the assumptions used in generating the simulations, as the orbital period and masses are not well known. From an analysis of the simulated positive superhump shape near superoutburst maximum, the maximum occurs near $\phi \sim 0.3$, when the disk is highly elliptical and eccentric and at least one of the two density waves is compressing with the disk rim. Based on the simulation, we find that the disk may be tilted and precessing in the retrograde direction at a time that is just before the next outburst and/or superoutburst.

1. Introduction

Non-magnetic, Cataclysmic Variable (CV), Dwarf Novae (DN) binary systems involve a white dwarf accreting matter from a close secondary star via Roche lobe overflow. If the white dwarf lacks a significant magnetic field, then the gaseous material from the secondary forms an accretion disk around the primary white dwarf. Examples include SU UMa systems, which have orbital periods fewer than a couple hours and have low enough mass transfer rates that allow the accretion disk to outburst and superoutburst. A consensus as to the cause of the periodic outbursts is a thermal instability in the accretion disk. Compared to an outburst, a superoutburst lasts longer, is about a magnitude brighter, and shows hump-shaped modulations in the light curve that have a period that is slightly longer than the orbital period (i.e., positive superhumps). Superoutbursts and positive superhumps are generally thought to result from a tidal instability from gaseous material that has reached or exceeded the 3:1 corotation resonance in the accretion disk, causing the disk to cyclically change from more circular to more elliptical and eccentric and then back to more circular over one positive superhump period. As a result of the torque, the disk is precessing in the prograde direction. For a more detailed review of the classifications of these systems, see e.g., Warner (2003).

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In addition to positive superhumps, some CV light curves show negative superhumps, or hump-shaped modulations that have a period that is slightly shorter than the orbital period. A consensus as to the cause of negative superhumps is a disk that is mis-aligned with respect to the orbital plane and precessing in the retrograde direction (see e.g., Montgomery, 2012a).

Sometimes both positive and negative superhumps are present in the same system simultaneously, indicating that the same accretion disk is precessing in the prograde direction as well as the retrograde direction at the same time. Although most CV permanent superhump systems have both precessions occurring simultaneously in the same disk, some lower mass transfer rate CV SU UMa systems also show both superhump modulations in the same light curve. Simulations of how the same CV accretion disk can precess prograde and retrograde at the same time are shown and discussed in Montgomery (2012b). In this work, we investigate the disk precessions in AW Sge, a CV SU UMa system.

AW Sge is a poorly observed SU UMa system, likely because it is faint, outburst intervals are long (286 ± 28 days, according to Lloyd, 2007), outbursts are of short duration (i.e., lasting only a couple days), and observing may be difficult if the field is located near the Sun or in the pre-dawn sky, when fewer observers are active. Few outbursts have been observed since the first in 1901: Lloyd and Pickard (2008) list 2000, 2002, 2004, 2006, and 2007 in the history of observed outbursts. On the night before the 2007 outburst, Lloyd and Pickard (2008) report $R \sim 17.6$, indicating that the system is coming out of quiescence [which is 18 −19, as determined from an analysis of the observations in the American Association of Variable Star Observers (AAVSO) archive (Shears et al., 2008)]. Although the maximum was not observed the following day, Lloyd and Pickard (2008) suggest the likely value is $V_{max} \sim 14.5$, similar to maximum brightness magnitudes found previously by others (e.g., Lloyd, 2007). As such, the net increase in brightness for the system is about five magnitudes. The time for the system to return to quiescence from maximum is about two additional days. From their data, Lloyd and Pickard (2008) find a weak cyclic $\delta V \sim 0.44$ magnitude modulation on the decline from maximum, but the find is not considered significant.

In 2006, AW Sge not only had an outburst, but it also had a superoutburst. This superoutburst lasted over eight days and is about a half-magnitude brighter at maximum than the typical outburst. From an analysis of the first four days into the superoutburst of their time-series data, Shears et al. (2008) find 0.25 magnitude positive superhumps occurring with a $P_+ = 0.0745(2)$ days period. This positive superhump period is slightly longer than their calculated orbital period of $P_{orb} \sim 0.0723(7)$ days. This stable positive superhump period is identical to that found during the 2000 superoutburst (Kato et al., 2003), a superoutburst that also lasted about eight days. During the first three or four days, the 2000 superoutburst maintained a brightness of 14.5 V magnitude and then faded rapidly over the next four days to 15.3 V magnitude at a rate of 0.18 mag/day, a rate like that seen in the 2006 superoutburst (Lloyd, 2007).

No publication to date has discussed negative superhumps in AW Sge. This suggests that these modulations may not occur in this SU UMa system, or may not yet have been observed, or may have been observed but not published.

As the first day of the 2006 superoutburst (e.g. Shears et al., 2008) is November 16, 2006 and the previous outburst occurred more than 2300 days earlier, we estimate that mid 2013 was when the next superoutburst cycle may have occurred. Our estimate falls short a few months, as the next superoutburst began in October 2013.

In this work, we report the time-series photometric observations of the October 2013 superoutburst in the R band. In addition, we simulate the peak in the superoutburst using 3D Smoothed Particle Hydrodynamics (SPH). In Section 2, we provide and discuss the observations. In Section 3, we provide and discuss the numerical simulations. In Section 4, we compare the simulation results with the observations, and we conclude in Section 5.

2. Observations

2.1. Observations and data reduction

On October 6, 2013, AW Sge was observed to have gone into outburst by Stubbings (vsnet-alert 16512) as well as by AAVSO observers. No superhumps were detected on this particular night. However, developing positive superhumps were detected on the next night. As Kato et al. (2014b) noted, a non-detection of positive superhumps on October 3–6 constrains the growth time of positive superhumps to no longer than 3.5 days.

Because of poor sky conditions, we began our observations four days later on October 11, 2013 and completed our observations on October 13, 2013. The duration of observational sets was ≃3 h on October 11, ≃6 h on October 12, and ≃6 h on October 13. Our time-resolved photometry was taken using a CCD Apogee 47 on the 60-cm telescope at the Sternberg Astronomical Crimean Station in the R band. Over these three days, we obtained more than 750 individual CCD images. Observations were made using two binning mode with 60 s resolution. The accuracy of our CCD observations is 2–3%.

We chose a reference star from the AAVSO list of comparison stars (labeled star 120) that has coordinates $\alpha\, 19^h58^m38^s$ and $\delta 16^o41'41''$; magnitudes $V = 11.^m975$ and $B = 12.^m265$; and a color index B-V = 0.290. As this reference star does not have a listed R magnitude, we constructed the light curves of AW Sge in units of relative magnitudes. As for check stars, all were taken from the close vicinity of AW Sge.

All our observational data have been reduced using the MAXIM DL standard package. Figs. 1–3 show the observational R light curves of AW Sge on October 11–13 in units of relative magnitude. These figures demonstrate the evolution of the positive superhump shape over the course of our observations on October 11–13.

As shown in the top panel of Fig. 1, the light curve is dominated on October 11 by a single hump-shape modulation. The maximum of each modulation (Kato et al., 2014a) occurs at JD 2450000 + 6577.31 and JD 2450000 + 6577.385, which is ∼25% after the previous minimum. Each modulation has amplitude $\delta R \sim 0.15$ and a period of 0.07465(30) days. As this period is a few percent longer than the orbital period, these modulations are identified to be positive superhumps.

By October 12, the positive superhump has evolved from a single-, to a triple-, hump shape modulation. As shown in the middle panel of Fig. 1, each positive superhump now has a dominant maxima followed by two minor peaks. The dominant maxima (Kato et al., 2014a) in each positive superhump occur at JD 2450000 + 6578.20, + 6578.28, and +6578.35 with a period 0.07499(20) days. The first minor peak in each positive superhump occurs at JD 2450000 + 6578.22, + 6578.30, and +6578.37, and the second minor peak occurs at JD 2450000 + 6578.24, + 6578.32, and +6578.39. The maxima occur ∼30% after the previous minima with amplitude $\delta R \sim 0.15$. The first and second minor peaks occur ∼59% and ∼88%, respectively, after the previous minima.

By October 13, the positive superhump has evolved from a triple-, to a double-, hump shape modulation. As shown in the bottom panel of Fig. 1, each positive superhump now has a dominant maximum followed by a minor peak. The dominant maximum (Kato et al., 2014a) in each positive superhump occurs at JD 2450000 + 6579.17, 6579.245, 6579.32, and 6579.39 with a period of 0.07614(20) days. The minor peak in each positive superhump occurs at JD 2450000 + 6579.20, 6579.28, and ∼6579.36. The maxima occur ∼43% after the previous minima with an average amplitude of $\delta R \sim 0.12$. The minor peaks occur ∼85% after the previous minima with an average amplitude of $\delta R \sim 0.04$.