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Photometric observations and Numerical modeling of SDSS J162520.29+120308.7, an SU UMa in the CV period gap

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HIGHLIGHTS

- Light curves during 2010 superoutburst and 2015 quiescence are presented.
- Observed Stage B P+ and P_{orb} are 0.090604(3) d and 0.09113(0) d,respectively.
- A single rebrightening is observed, an unusual event for an SU UMa system.
- 3D SPH simulation produce Stage AP+ = 0.09717d and Stage BP+ = 0.09702 d.
- An average secondary-to-primary mass ratio q = 0.21(1) is suggested for this system.

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ABSTRACT

We present R-band photometric observations of Cataclysmic Variable dwarf nova SU UMa SDSS J162520.29+120308.7 during the July 2010 superoutburst, from near maximum through decline and into a single rebrightening. We find a maximum superoutburst amplitude of ∼ 6.1 magnitudes and a maximum rebrightening amplitude of ∼4 magnitudes. Near superoutburst maximum, we find 0.09604(3) days for the mean Stage B positive superhump period and a much longer period for the hump shaped modulation during the rebrightening. For the orbital period, we find P_{orb} = 0.09113(30) days. As all periods both agree and disagree with values reported by others, additional observations are needed. Our 2015 observations of this system in quiescence reveal a 0.09080(20) day orbital period. As our 2010 value is within the error bars of a spectroscopically determined value and our 2015 photometrically determined value, we suggest 0.09113(30) days as the orbital period for this system. As for the secondary-to-primary mass ratio, analytical models using observed orbital and Stage B positive superhump periods as input suggest $q = 0.221$. As a check, we present a 3D SPH simulation of the rise to, and during the plateau stage of, the SU UMa in superoutburst, assuming P_{orb}=0.09113 days. For Stages A and B, we find 0.09717 days and 0.09702 days, respectively, for the average simulated positive superhump periods. Analytical models using these simulated Stages A and B and the simulated orbital period suggest $q = 0.1920(4)$ and $q = 0.221$, respectively, for this system. Due to the poorly constrained observational data and the similar mass ratio estimates regardless of stage, we can neither confirm nor deny that Stage A is better than Stage B for determining mass ratio in CV dwarf novae SU UMa systems. Additional observations and simulations are needed to further test this recently proposed hypothesis. For now, we suggest an average $q = 0.21(1)$ for this system.

1. Introduction

Cataclysmic Variable (CV) binary systems involve a white dwarf primary accreting matter from a close, low mass, main sequence secondary through the inner Lagrange point via Roche lobe overflow. If the white dwarf primary is considered non-magnetic, then the gaseous material flowing from the inner Lagrange point forms an accretion disk around the primary. The dwarf novae (DN) class of CVs involves a thermal instability in the disk that leads to a disk outburst, which results in a brightening the system by several magnitudes as the disk is drained of material. The SU UMa subclass of CVs usually have lower mass transfer rates, lower than nova likes, and shorter orbital periods of ∼2.5 hours or fewer. The accretion disks not only experience outbursts but also

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superoutbursts, which are longer in duration, occur much more infrequently, and are about a magnitude brighter. In addition, the light curves show ~0.3 mag amplitude hump-shaped modulations, the period of which is a few percent longer than the orbital period (i.e., positive superhumps). Superoutbursts and positive superhumps are generally thought to result from a tidal instability that occurs when enough gaseous material is near the 3:1 co-rotation resonance radius in the accretion disk, causing the disk to be torqued by the secondary into cyclically changing 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's line of apsides rotates very slowly in the prograde direction. For a more detailed review, see e.g., Osaki (1996) and Warner (2003).

In addition to positive superhumps, some CV light curves show cyclic negative superhumps, which have a period that is a few percent shorter than the orbital period. A consensus as to the cause of negative superhumps is a mis-aligned disk. Tidal torques on the mis-aligned disk cause the disk's line of nodes to slowly rotate in the retrograde direction (see e.g., Montgomery, 2012a). Sometimes both positive and negative superhumps are simultaneously present in the same system, indicating that the same accretion disk is simultaneously precessing in the prograde and retrograde directions. Sometimes, one superhump modulation is present at a time (e.g., TT Ari), indicating that the disk changes from precessing in the retrograde direction to precessing in the prograde direction and then back to the retrograde direction (e.g., Vogt et al., 2013). Although most CV permanent superhump and nova like 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).

Here, we investigate disk precessions and orbital periods in SDSS J162520.29 + 120308.7 (hereafter called SDSS J1625), a CV dwarf novae. SDSS J1625 became a target of interest by Wils et al. (2010) since its initial candidacy as a CV by Drake et al. (2009). While monitoring SDSS J1625, the Catalina Real-time Transient Survey detected a bright transient on July 5, 2010 (CSS100705: 16250 + 120309), alerting the CV community of a superoutburst and possibly Stage A positive superhumps (vsnet-alerts 12051, 12054, 12059, 12061, and 12062). Approximately four-to-five days into the superoutbutst, the system's brightness rapidly declined unexpectedly and then rebrightened. During Stage B of the superoutburst, the fully developed stage that has a systematically varying positive superhump period, Kato et al. (2010) find $P_+ = 0.09605(5)$ days for the mean positive superhump period based on a timing analysis. Olech et al. (2011) find $P_+ = 0.095942(17)$ days, which is about 9.3 seconds shorter. As noted by Olech et al. (2011), the positive superhump period was not stable; it rapidly decreased at a rate P_{dot} = -1.63(14)x10^{-3} at the beginning of the superoutburst and then increased at a rate P_{dot} = 2.81(20)x10^{-4} during Stage B. At the end of the superoutburst, which is in Stage C, Olech et al. (2011) find the period had stabilized to $P_+ = 0.09531(5)$ days. Because the periods observed in Stage B differ, we investigate in this work our time-series photometric observations of the same July 2010 superoutburst in the *R* band.

In this work, we also investigate how mass ratios are estimated for SU UMa systems: Kato et al. (2014) suggest mass ratios should be estimated using Stage A data whereas historically mass ratio estimates are found using Stage B data. As the mass ratio suggested by Kato et al. (2014) using Stage A data differs from that by Olech et al. (2011) using Stage B data, we provide 3D Smoothed Particle Hydrodynamics (SPH) simulations and analyze our own observational data. 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 in Section 5, we provide conclusions.

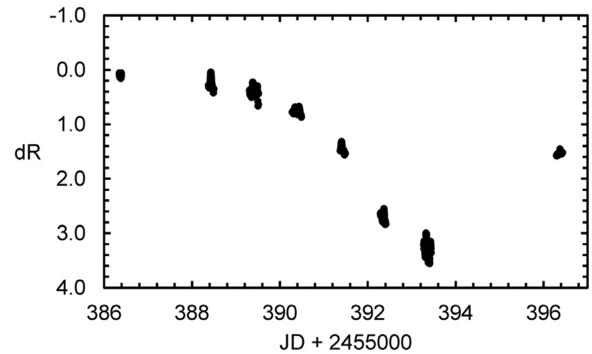

Fig. 1. Superoutburst light curve of SDSS J1625 shows the relative brightness variations in the R band from July 8, -18, 2010 (JD 2455000+). The light curve starts in the plateau phase, which is followed by a rapid decline and a rebrightening.

2. Observations

2.1. Observations and data reduction

On July 5, 2010, dwarf novae candidate SDSS J1625 Wils et al. (2010) was observed to be in outburst by the Catalina Real-time Transient Survey (see vsnet alert 12051–12053). Our observations be gan three days later, on July 8, (Fig. 7) when the system was near maximum superoutburst. Our observations ended ten days thereafter (i.e., July 18, 2010).

Our time-resolved photometry is taken using a CCD Apogee 47 on the 60 cm telescope at the Sternberg Astronomical Institute Observational Station in the *R* band. Our observations are made using two binning modes and using 60 sec integration times. Exposure times last between 100–120 seconds, and the numbers of exposures range from 37 on the first night to more than 75 on the other nights. The duration of observations ranges from 2 to 5 hours per night. For each frame, the variable brightness of the star is compared to an ensemble of check stars (at 16:25:19.19 + 12:04:39.6 and 16:25:10.29 + 12:02:15.7) and to a comparison star [at 16:25:24.31 + 12:01:19.3, of mag V = 14.459(059), and color index $B - V$ = 0.879(122)] using the AAVSO Photometric All-Sky Survey (APASS). Our photometric data are accurate to 1–2% for all CCD observations.

As the comparison star does not have a listed *R* magnitude, we construct light curves of SDSS J1625 in units of relative magnitudes. All our observational data are reduced, and differential magnitudes obtained, using the MAXIM DL standard package.

Fig. 1 shows brightness variations of SDSS J1625 in units of relative magnitude *dR* over the entire observing run, and is similar to a figure in Voloshina et al. (2011). As shown, the plateau phase of the superoutburst lasts at least two days. During this phase, the system fades at a rate of 0.08(5) mag d^{-1}. The rate of decline during this plateau phase is approximately linear in the *R* band, unlike the finding of a parabolic decline in the *V* band observed by Olech et al. (2011). Then the system enters into a rapid decline phase for the next five days at a rate of 0.42(6) mag d^{-1}. The shape of this decline phase resembles that in the *V* band light curves by Kato et al. (2010) and Olech et al. (2011). Two days later, the system rebrightens (i.e., an echo outburst), which is an uncommon event for this type of system.

Fig. 2 is an expanded version of Fig. 1 and shows the structure of the light curve on each night of the superoutburst. As seen in the panel labeled 386, the data is limited as clouds formed in the