Optical Time-Series Photometry of the Peculiar Nova CSS081007:030559+054715

Matthew Templeton
AAVSO Headquarters, 49 Bay State Road, Cambridge, MA 02138; matthewt@aavso.org

Robert Koff
980 Antelope Drive West, Bennett, CO 80102; bob@antelopehillsobservatory.org

Patrick Wils
Aarschotsebaan 31, Hever B-3191, Belgium; patrickwils@yahoo.com

Arne A. Henden
AAVSO, 49 Bay State Road, Cambridge, MA 02138; arne@aavso.org

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Abstract We present an analysis of optical photometry of the transient optical and X-ray source CSS081007:030559+054715. Unfiltered CCD observations were made between 2008 December 17 and December 30 (JD 2454817.5 to 2454830.5), showing variability at the level of 0.5 magnitude. Time-series analyses of these data confirm the existence of the 1.77-day period detected in X-ray, UV, and optical wavelengths by the Swift satellite. The maxima of the optical and X-ray emission appear to be out of phase.

1. Introduction

The variability of CSS081007:030559+054715 (hereafter CSS081007) was discovered after its significant brightening was detected by the Catalina Real-time Transient Survey (CRTS; Drake *et al.* 2009a) on 2008 October 7. The object was observed spectroscopically by Pejcha *et al.* (2008), who found broad emission lines of H-α, HeII, and [OIII] with multiple, high-velocity components indicative of nova ejecta. Schwarz *et al.* (2008) observed this object with the Swift satellite in both X-rays and ultraviolet; the X-ray spectrum indicated this object is a supersoft source, which is a common feature of accreting white dwarfs undergoing current or recent thermonuclear burning. Further X-ray observations by Beardmore *et al.* (2008) and Osborne *et al.* (2009) indicated both a significant brightening of the source in X-rays, along with an apparent periodicity of about 1.77 days. Analysis of pre-outburst photometry from CRTS by Drake *et al.* (2009b) indicated that the progenitor was highly variable, but that there was no evidence for a period of 1.77 days in the optical data, and dedicated *BVRc* photometry by Goranskij and

Metlova (2009) obtained over thirteen sparsely-distributed nights between 2008 December 3 and 2009 February 19 indicated marginal evidence for periodicity at 1.694 and 0.6106 days.

2. Data

The AAVSO requested observations of this star on 2008 December 12 (Templeton 2008), and R. Koff commenced a two-week series of nightly time-series of CSS081007. Unfiltered observations were made using a 0.25-meter SCT with an Apogee AP-47 CCD camera; the telescope is located near Bennett, Colorado. Differential photometry was performed using GSC 00061-01278 as the comparison star and GSC 00061-01257 as the check star. The unfiltered magnitudes are relative to the *V*-band zero point of 14.862 for the comparison star, as obtained by calibration data by A. Henden. We note that a full *BVRcIc* calibration of this field was obtained by Henden using the Sonoita Research Observatory, and is available from the AAVSO website.

Eleven nights of photometry were obtained between JD 2454817.55 (2008 December 17.05) and 2454830.66 (2008 December 30.16), yielding a total of 874 observations of the variable. Photometry of the comparison and check stars showed that both were constant with standard deviations of about 0.02 magnitude throughout the two-week run. The resulting light curve of CSS081007 is shown in Figure 1.

3. Analysis

The time-series data were analyzed using a deconvolving, cleaning Fourier transform (Roberts *et al.* 1987), and we found the strongest peak at P = 1.767 ±0.001 days. We found evidence for a weaker peak at 0.638 day. These two peaks are separated by one cycle per day in the frequency domain, and one is almost certainly an alias of the other. Based upon the phase diagrams of these data, and on the Swift results which do not have the same sampling issues, we believe the longer period of 1.767 days is the true period.

Figure 2 shows the data folded with four different periods using the X-ray zero phase point of HJD 2454807.1245 from Osborne *et al.* (2009). The plot at top left shows the optical data folded with the 1.767-day period, with the 0.638-day period at top right; the Goranskij and Metlova (2009) periods of 1.694 and 0.6106 days are shown at bottom left and right, respectively. The optical light curve phases most cleanly with the period of 1.767days, which is a good indication that the periodicity exists and our calculated period is consistent with its real value. We note that the bright segment located at a phase of 0.95 to 1.0 was observed on 2454817, making it the earliest portion of the light curve. It is possible the object declined after this night; however, the remaining data appear to have a reasonably constant mean afterward. Our second period of 0.638 can phase the data, but there is clearly more phase dispersion on the rising branch. Both of the Goranskij and Metlova periods are ruled out by both Fourier analysis and the phase diagrams.

The morphology of the light curve is difficult to characterize given the relatively small amount of data available, the (likely) aperiodic rapid variability, and the varying mean light level due to evolution of the nova outburst. The simplest interpretation is that the light curve consists of a single deep minimum lasting for nearly half a cycle, with little or no evidence of a secondary eclipse. There is a very weak dip at maximum, around phase 0.1, but it is well below the level of scatter in the data when binned. The main eclipse is not symmetrical; the decline to minimum is at least 30 percent of the orbit, while the rise to maximum is about 10 percent. Aside from the bright segment of data around phase 0.35–0.4, the light curve appears to be stable throughout the two-week span of observations; therefore the overall morphology of the system did not appear to change appreciably during the observing run. Osborne *et al.* (2009) noted that their ephemeris yields the time of *minimum* in the X-ray. Figure 2 shows that this corresponds to a *bright* phase of the optical light curve, which indicates that the optical and X-ray emission come from two different locations within the system that are eclipsed or obscured at different times.

4. Discussion

These optical data strongly support the presence of a 1.767-day period in CSS081007. We believe the weaker detection and slightly different period found by Goranskij and Metlova is a product of their sparser sampling covering a broader span of time. Given the underlying nova event, the longer span of data may be significantly affected by the evolution of the nova light, complicating the analysis of the time-series. The AAVSO data phase with essentially the same period as the Swift X-ray and UV periods, although there is a significant phase shift between the optical and X-ray. Further time-series observations of the system would provide additional useful constraints for light curve modeling in both the optical and X-ray. The slow optical evolution of this outburst suggests a peculiar nova, and stronger constraints on the geometry of the system and the nature of its components would greatly aid in our understanding of this system.

References

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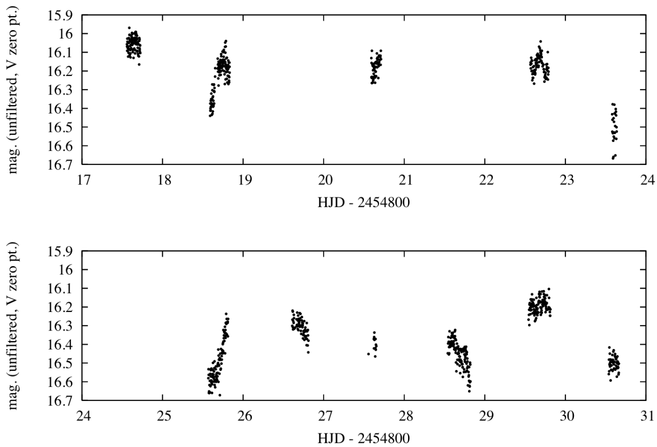

Figure 1. The unfiltered light curve of CSS081007 from 2008 December 12 to December 30 (JD 2454817.5 to 2454830.5). The average photometric error per point is about 0.025 magnitude.

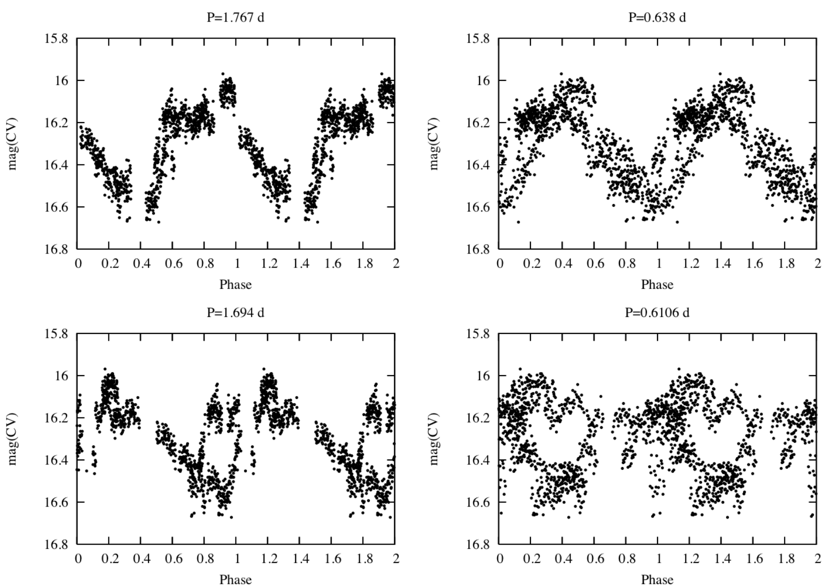

Figure 2. The light curve of CSS081007 folded with four different periods: (top left) 1.767 days; (top right) 0.638 day; (bottom left) 1.694 days; (bottom right) 0.6106 day. All four phase diagrams use the time of X-ray minimum (HJD = 2454807.1245) from Osborne *et al.* (2009) as the zero phase reference. The period of 1.767 phases much more cleanly than any of the other three. Comparison of the optical light in the 1.767-day period phase diagram shows that the optical light is near maximum during the X-ray minimum; phase=0.0 in the X-ray light is still optically bright.