Determining the Orbital Period of the Cataclysmic Variable CSS1204 Using Data from the Vatican Advanced Technology Telescope

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Abstract: *Using time-resolved photometry from three nights of observing at the Vatican Advanced Technology Telescope (VATT), we obtained light curves of the cataclysmic variable (CV) CSS1204 (RA.11:11:26.87 Dec.+57:12:38.9(J2000)).From these observations, we calculated the power spectrum of CSS1204 and determined the orbital period of the binary. We determined the orbital period for CSS1204 to be 0.8876 hours. Using the orbital period along with the pre-determined superhump period (p=0.9370 h), we can infer the mass ratio of the primary and secondary stars in this CV. We calculated a mass ratio of 0.458 using the fractional superhump excess for the minimum superhump period (P_{SH}) which was used in Kato et al. 2009.CSS1204 is unusual in that its period is approximately 25 minutes below the period minimum for hydrogen-rich CVs. The research outlined in this paper will be included in a forthcoming journal article about this star.*

Keywords: *CSS1204, cataclysmic variable, orbital period, VATT*

Introduction

"Cataclysmic variables (CVs) are compact binary systems in which the surface gas of a secondary star overflows and is accreted by a more massive white dwarf" (qtd. in Uemura, et al 2001). A disk consisting of infalling matter forms around the primary star due to the angular momentum that needs to be conserved. In the accretion disk, viscosity occurs and as a result, the disk material loses it angular momentum and eventually is accreted on the white dwarf star. When the density and temperature of the hydrogen layer in the accretion disk around the white dwarf rises to a considerable amount, an event known as a cataclysmic outburst (or superoutburst) will take place. During outbursts and superoutbursts, the system becomes much brighter. When observing a CV during a superoutburst, an additional modulation will appear in the light curve of the star, called a superhump. This event is caused by the precession of the accretion disc and it can occur approximately every 20-300 days depending on the CV itself. The orbital periods of CVs are typically only several hours long with an observed period minimum close to 78 minutes. Very few CVs have orbital periods between 2-3 hours. This duration of time is known as the period gap.

CSS120422:111127+571239 (more commonly known as SBS 1108+574) is classified as a CV like the one mentioned above. It was first observed by the Catalina Real-Time Transient Survey (CRTS) during an outburst. As a result of later observations from the Japanese-run network, VSNET and Peter Garnavich, the binary star in CSS1204 was specifically classified as a SU UMa star. Garnavich, et al (2012) reported spectra showing strong Hydrogen emission along with the expected abundance of Helium emission present. Before this discovery, it was assumed that CSS1204 was a AM CVn star which are ultrashort-period CVs with no amounts of hydrogen in their spectra. “Stars which show both superoutbursts and superhumps are referred to as SU UMa stars” (Hellier, 2001). “Superhump oscillations with a period of 0.93 hours” were observed from CSS1204 (Garnavich, et al 2012). Superhumps are caused by the gravitational interaction between the disk and the secondary star. When the disk becomes asymmetric and precesses, it causes fluctuations in brightness which usually last slightly longer than the orbital period of the CV.

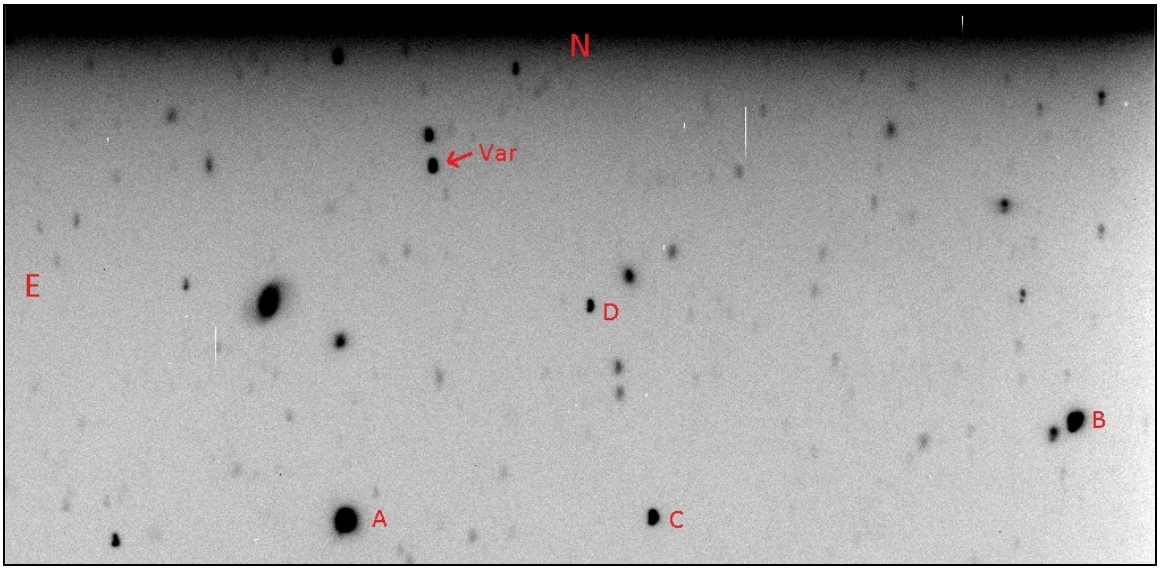


Figure 1. A summed “superCSS1204” FITS image showing the variable star and the four nearby comparison stars. Star A is the comparison star used in the aperture photometry. Var is the CV CSS1204.

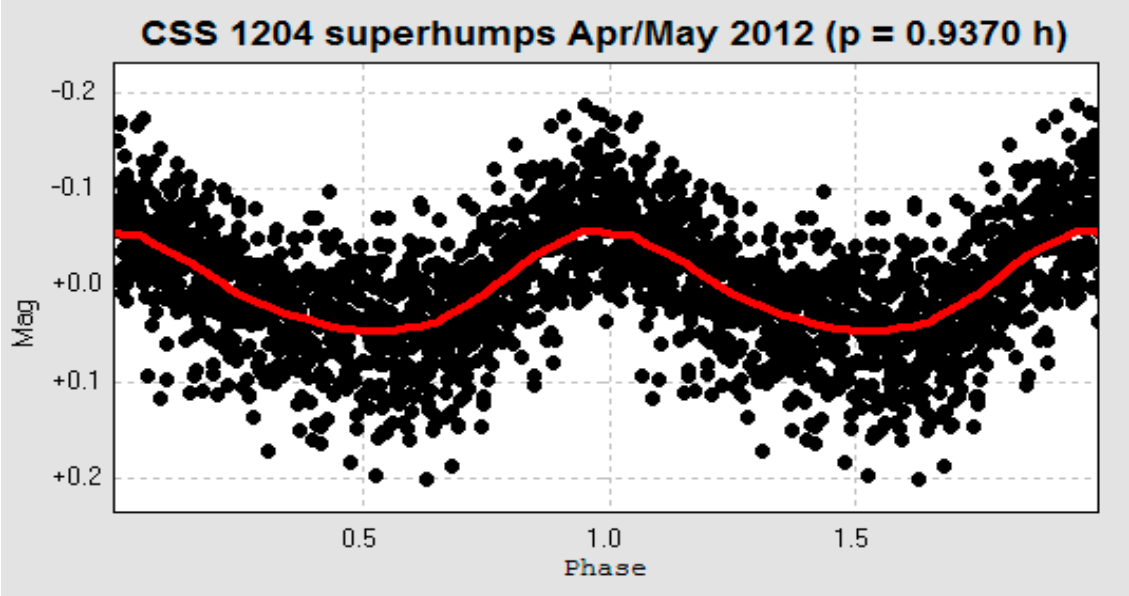


Figure 2. This image[1] shows the Magnitude vs. Phase plot for the superhump period of CSS1204.

The purpose of this paper is to describe the process and results from analyzing the power spectrum of CSS1204, in order to determine the orbital period. The superhump period for the CV CSS1204 is already known, but an orbital period in the quiescent state has yet to be determined. Knowing the orbital period for CSS1204 along with the pre-determined superhump period will allow us to derive the mass ratio of the primary white dwarf to the secondary star. If our orbital period is close to the superhump period determined by VSNET, then there will be a large mass ratio between the two components in the CV, but if our period is much shorter than the superhump period, the mass ratio of the primary and secondary stars will be small. The mass ratio of this CV contains clues as to the nature of the secondary "donor" star. Comparing the superhump period to the true orbital period of CSS1204 is the only method that will allow us to discover these clues.

[1] This plot of the superhump period for CSS1204 was created by Univ. of Notre Dame School of Law student, Colin Littlefield.

Materials and Methods

Situated atop Mt. Graham in Safford, Arizona, the VATT is operated by the Vatican Observatory in partnership with the University of Arizona. Its primary mirror consists of a 1.83-m f/1.0 mirror. The location of the VATT atop Mt. Graham provides one of the best areas in the U.S. for seeing even without the use of adaptive optics. Observations of CSS1204 were recorded through the Blue (FWHM-94nm) and Red (FWHM-138nm) filters within the visible light spectrum. The CCD (Charge Coupled Device) used in the VATT is a STA0500A back illuminated 4k CCD. On the third night of observation, a thunderstorm passed over Mt. Graham creating bad seeing so as a result, CSS1204 was not observed.

Image Reduction and Analysis Facility (IRAF) is a software system that we utilized to prepare the images taken from the VATT. To extract chip [2] data from the original mosaic files, we used the *imcopy* package for each night's pixel data. Once the chip [2] data was extracted from the original mosaic files, bias images (exposures taken when the camera's shutter is left shut) were combined using the *imcombine* package. Bias images are important in the image reduction process because they eliminate readout noise from exposure to exposure and allows for better measurements of the star photometry. This created a "supersmallbias" which we subtracted from the CSS1204 FITS files using the *imarith* package.

Using the IRAF package, *qphot*, we performed aperture photometry on all of the biased CSS1204 FITS images. Photometry is the use of an electronic detector to measure the amount of flux from an object in a given region of the spectrum. The atmosphere absorbs and scatters some light from the target star, the flux of the target star will change depending on the amount of atmosphere along the line-of-sight from Earth, so to lessen the impact the atmosphere has on the

flux of the target star, we need to compare it to a few nearby stars. We wanted to ensure that the variation in magnitude we were seeing was strictly from the target star and not due to the variation in seeing conditions from night to night, so we subtracted the magnitude of the brightest comparison star (Comparison star A) with the most constant flux from the magnitude of our target star. To do this, we configured the parameters in *qphot* accordingly, created MAG files from each star, subtracted the Comp 1 star MAG file from the variable MAG file, and then subtracted the mean of the magnitudes as well. It should be known that the last two FITS images from night 2 were not included in the corresponding MAG files because during the time that these exposures were being taken, a glitch occurred in the telescope causing it to change coordinates.

Interactive Data Language (IDL) is a programming language used to analyze large quantities of data. Using this program language, we used the program *power.pro* created by Peter Garnavich and created the program *n1power.pro* to run in conjunction. The program *power.pro* calculated the power spectrum of the star with a low frequency of 0.1 cycles/hour and a high frequency of 10 cycles/hour out of 10,000.0 frequencies. We compiled *n1power.pro* to plot the magnitude difference of CSS1204 vs. the phase (cycle). To reduce the noise present in the plot, we applied a 3-pixel *boxcar smooth* function to the data.

Data

Figure 3 is a light curve which shows the relationship between the relative magnitude and the phase of CSS1204. The phase is measured in cycles or time (hours) per period. As the stars orbit their center of mass, the observed flux from the system will change as some features come into

view and others become hidden. Since the orbital period is stable, these changes in brightness should repeat themselves during every orbit.

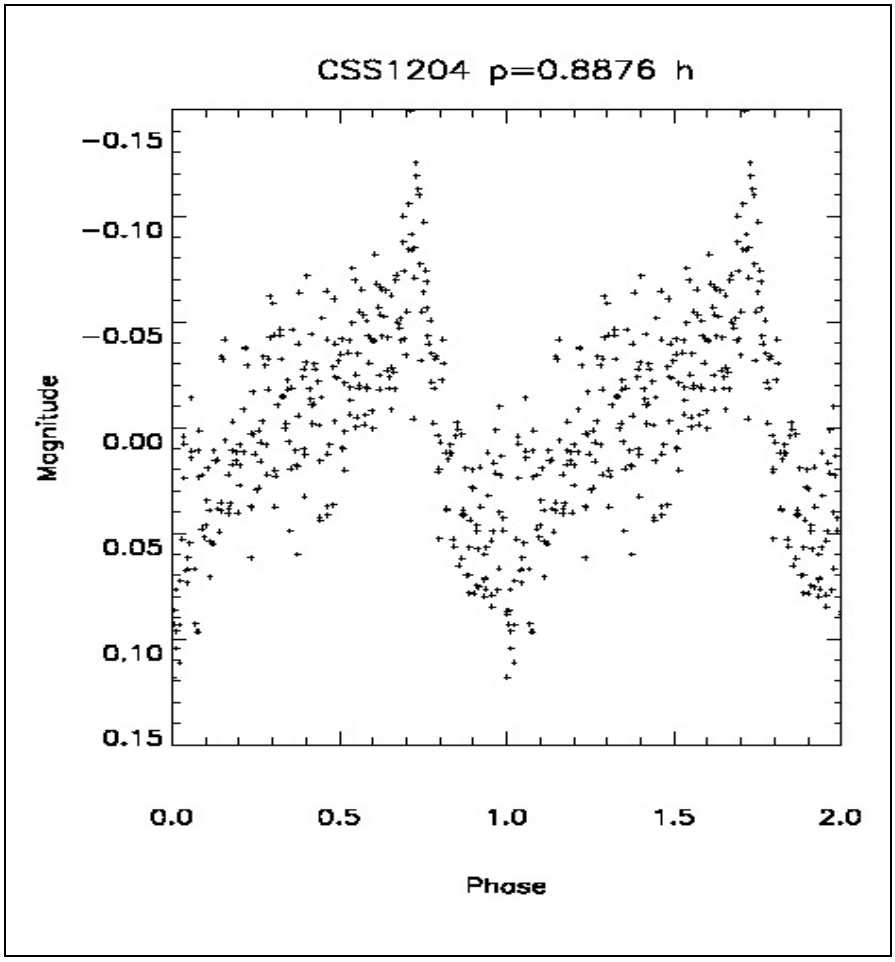


Figure 3. This image shows the Magnitude vs. Phase plot we created for CSS1204.Two phases (cycles) are shown for clarity.

Results and Analysis

After three nights of observing the CV CSS1204 at the VATT, we determined that the orbital period was 0.8876 hours in duration. Looking at this value as well as the superhump period (0.9370 h) one can see that they are close in comparison. To determine the mass ratio of the

components in CSS1204, we used the fractional superhump excess for the minimum superhump period (P_{SH}) which was used in Kato et al. 2009

$$\varepsilon = 0.25q^2 + 0.16q \quad (1),$$

where q represents the mass ratio of the secondary star to the primary star and $\varepsilon = \left(\frac{P_{SH}}{P_O}\right) - 1$; P_{SH} represents the superhump period, and P_O represents the orbital period. The calculated mass ratio was 0.25175 or 25.2%. This makes the empirical assumption that the secondary star is approximately 1/4th the size of the primary star.

Conclusion

Using time-resolved photometry from three nights of observing at the Vatican Advanced Technology Telescope, we calculated the true orbital period and the mass ratio of the cataclysmic variable, CSS120422:111127+571239. From these values, one can see that the components in this CV are distanced extremely close to each other-even closer to each other than the distance of Mercury and our Sun. The research outlined in this paper will be included in a forthcoming article about this star.

References

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