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OBSERVATIONS OF SS CYG – QUIESCENCE TO OUTBURST

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ABSTRACT

We collected data at both the SARA telescope at Kitt Peak National Observatory and at the Ball State University Observatory to investigate the behavior of the cataclysmic variable binary system SS Cygni. The majority of our data covers the system's quiescent state, while the last two nights show the rise to outburst and the outburst. We investigated changes in the temperature and radius of the accretion disk over time.

Subject headings: stars: novae: cataclysmic variables – individual stars: SS Cyg

1. INTRODUCTION

In order to clarify the complex physical processes that cause dwarf nova (DN) outbursts, we chose to observe the well-known system SS Cyg due to its frequent outbursts and over all brightness. The goals were to capture the system's rise to outburst in order to identify behavior that might signal the start of a typical outburst and test DN outburst models. Most of our data were collected during quiescence. These data were analyzed for periodicities and any pre-outburst indicators.

2. METHODS

We began by obtaining images of SS Cyg with the 0.9 m SARA telescope located at the Kitt Peak National Observatory. The images were taken with a U-42 CCD camera on nights of June 2, 3, 4, and 5 of 2006 using B, V, R_c, and I_c filters. We observed ten other nights at the Ball State University Observatory in Muncie, Indiana using a 14" telescope with an ST-8 CCD camera. These observations were made on June 9, 13, 14, 15, 16, 17, 20, 23, and 24 (UT). However, on the night of outburst (beginning June 25), we collected data on a 16" telescope equipped with an ST-10 CCD camera and B, V, R_c, and I_c filters. Table 1 shows the full summary of the nights SS Cyg was observed and instruments used.

TABLE 1
SUMMARY OF OBSERVATIONS

Date (UT)	Site	State
June 3	SARA (On location) BSU (Meade-16")	Quiescence
June 4	SARA (On location) BSU (Meade-16")	Quiescence
June 5	SARA (On location)	Quiescence
June 6	SARA (On location)	Quiescence
June 9	BSU (Celestron-14")	Quiescence
June 13	BSU (Celestron-14")	Quiescence
June 14	BSU (Celestron-14" & Meade-16")	Quiescence
June 15	BSU (Celestron-14" & Meade-16")	Quiescence
June 16	BSU (Celestron-14")	Quiescence
June 17	BSU (Celestron-14")	Quiescence
June 20	SARA (Remote) BSU (Celestron-14")	Quiescence
June 22	BSU (Celestron-14")	Quiescence
June 24	BSU (Celestron-14")	Night of rise
June 25	BSU (Meade-16")	OUTBURST

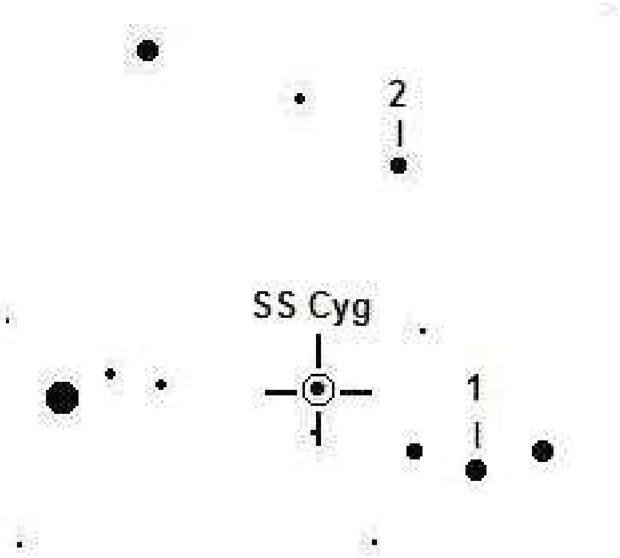

FIG. 1.— Star field chart of SS Cyg (Approximately 9' X 10', north up, east left)

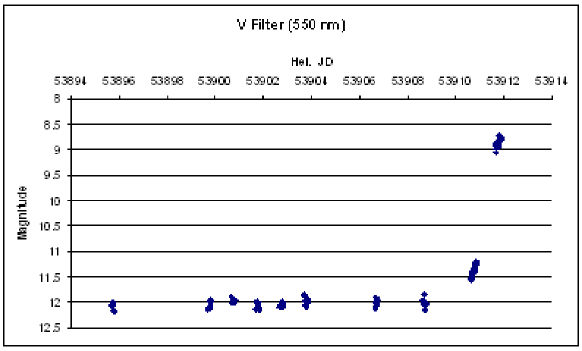

FIG. 2.— Magnitudes (V-Filter) versus time

The raw data were processed with IRAF. Each image was bias subtracted, dark subtracted and divided by the filter-appropriate flat field image. The aperture photometry was done using CCDIR (Unified Software Systems). The SS Cyg star field is shown in Figure 1, the variable star (marked "SS

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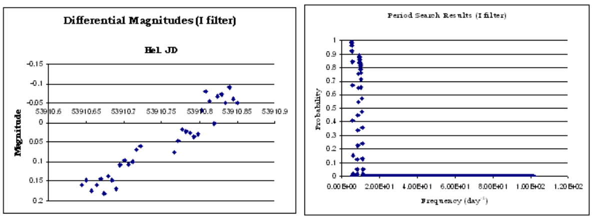

FIG. 3.— Left: 2006 June 24 (UT) The light curve for the start of the outburst. Right: The period search results for that night.

Cyg"), the comparison star (marked "1") and the check star (marked "2") are shown in Figure 1.

We solved for transformation and extinction coefficients using secondary standard stars provided by A. Henden (AAVSO). Standardized V magnitudes and color indices (B-V), (V-R), and (R-I) were calculated. Figure 2 shows the V light curve for quiescence and the rise to outburst.

A black body approximation was used to calculate the color temperature of the system as a function of time. This was done by least-squares fit of a black-body to the three color indices. The color temperatures and the observed flux changes were then used to find the accretion disk radius as a function of time. The ratio of the observed flux at outburst, F_{O}, to that in quiescence, F_{q}, is related to the magnitude change by:

$$m_{\mathrm{q}} - m_{\mathrm{O}} = -2.5 \log \left(\frac{F_{\mathrm{q}}}{F_{\mathrm{O}}} \right) \qquad (1)$$

For an optically thick circular disk this can be approximated by

$$m_{\mathrm{q}} - m_{\mathrm{O}} = -2.5 \log \left(\frac{r_{\mathrm{q}}^2 B(T_{\mathrm{q}})}{r_{\mathrm{O}}^2 B(T_{\mathrm{O}})} \right) \qquad (2)$$

where r is the accretion disk radius and $B(T)$ is the Planck function. The ratio of the disk radius at some time in outburst compared to quiescence is

$$\frac{r_{\mathrm{O}}}{r_{\mathrm{q}}} = \sqrt{10^{0.4\Delta m} \frac{B(T_{\mathrm{q}})}{B(T_{\mathrm{O}})}} \qquad (3)$$

3. RESULTS

During analysis, we observed systematic changes in magnitude and decided to check for periodicity in these variations. The results of a period search during the night of the rise to outburst(2,453,910) are shown in Figure 3. The period search technique is that of Scargle (1982) and modified by Horne and Baliunas (1986). The period search, Figure 3(right), shows a peak in the probability plot at about ~2.5 hours. This periodicity is not apparent on any other night. It could be due to changes in the disk related to the onset of the outburst. We found no evidence of any pre-outburst changes such as the 0.1 mag brightening reported by Hill and Waagens for SS Cyg. This type of brightening was also seen in TW Vir by Mansperger and Kaitchuck (1990). However we did find light variations seen in quiescence of ±0.1 - 0.2 mag.

The color-color diagrams (Figure 4) show an evolution from quiescence to outburst that is roughly parallel to the blackbody curve. No corrections were made for interstellar reddening which is difficult to estimate (see Grant and Abt 1959).

These graphs indicate the blackbody approximation for the disk is reasonable in the V, R and I bandpasses. Figure 5 shows the color temperature versus time. During the night the outburst began, the temperature increased approximately 270 K. The next night showed an increase of approximately 15,000 K compared to quiescence.

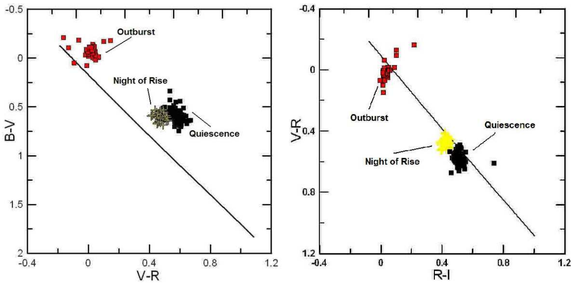

FIG. 4.— Left: B-V versus V-R. Right: V-R versus R-I.

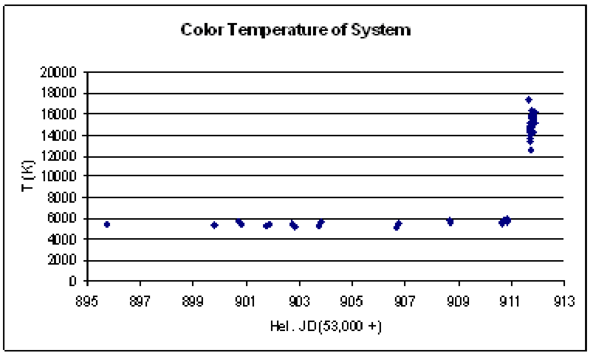

FIG. 5.— Color temperature (K) versus time

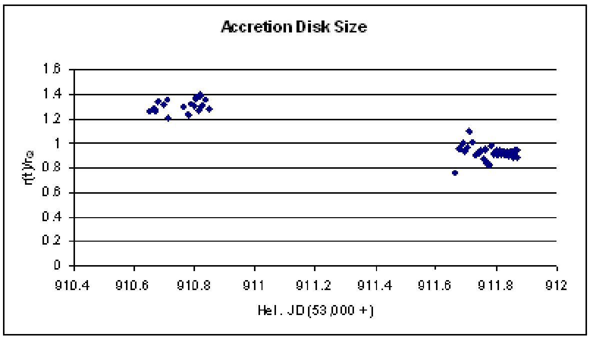

FIG. 6.— Accretion disk radius changes over time

The calculated disk radius (compared to quiescence) over time is seen in Figure 6. This indicates that the disk had increased in size during the early stage of the outburst and then shrank slightly below the quiescence radius before reaching maximum light.

4. CONCLUSIONS

The period search found a periodicity of ~2.5 hours when SS Cyg began its rise to outburst. This could be due to changes in the disk related to the onset of the outburst. The color-color diagrams show the disk to be a good approximation to a blackbody at longer wavelengths. Surprisingly, this appears to be true even in quiescence. In the first hours of the outburst the color-temperature of the disk rose about 270 K while the disk radius increased by ~30%. Twenty four hours later the disk was about 15,000 K hotter, 2 magnitudes brighter but ~10% smaller than its size in quiescence. This behavior is different from U Gem where the disk size increases at outburst and slowly declines until quiescent brightness is reached (Warner 1995). Further multi-color observations of outburst are needed to determine if the 2006 June 25 outburst was unique in this manner.

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