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V963 CYGNI IS AN ACTIVE DETACHED BINARY WITH A 33.5 HOUR PERIOD

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As a part of our study of observationally neglected eclipsing binaries we observed the eclipsing binary V963 Cygni, [GSC 2656-1995, $\alpha(2000) = 19^{\rm h}44^{\rm m}4\overset{\rm s}{.}92$, $\delta(2000) = 31^\circ 41' 50\overset{''}{.}2$]. Wachmann (1961) discovered this variable and reported 21 times of minimum light and the ephemeris

$$\text{HJD Tmin I} = 2434629.397 + 0.6973\text{d} \times \text{E}. \tag{1}$$

From his photographic light curves he classified this as an Algol. Sixteen subsequent times of minimum light have appeared in the literature (Safár and Zejda 2000, and 2002, Agerer and Hübscher 2000, Dvorak 2005, Hübscher 2005, Hübscher, Paschke, and Anton 2005, Hübscher, Paschke, and Walter 2005 and 2006, Hübscher, Paschke, and Walter 2006, Hübscher and Walter 2007).

Our $UBVRI$ light curves were taken on 19-25, July, 2004 by NCH, RGS, and DRF with the Lowell 31 inch reflector in Flagstaff, AZ through the National Undergraduate Research Observatory (NURO). The CCD camera was liquid nitrogen cooled, and the chip was a metachrome coated TEK 512×512. Sixty-nine observations were taken in U, 94 in B, 125 in V, 105 in R and 96 in I. Our observations, variable minus comparison delta magnitudes are given in electronic Table 1 (available through the IBVS-website as `5786-t1.txt`). The stars [GSC 2656-3363, $\alpha(2000) = 19^{\rm h}44^{\rm m}03\overset{\rm s}{.}64$, $\delta(2000) = 31^\circ 41' 13\overset{''}{.}3$], and [GSC 2656-2055, $\alpha(2000) = 19^{\rm h}44^{\rm m}16\overset{\rm s}{.}91$, $\delta(2000) = 31^\circ 41' 31\overset{''}{.}6$], were used as comparison and check respectively. A finding chart of V963 Cyg (V), the comparison (C), and the check star, (K) are given in Figure 1.

Early in the observing run we discovered that the two consecutive deep eclipses were of different depths, ~ 0.78 and ~ 0.67 magnitudes in V, respectively. There was no hint of a shallow secondary eclipse as expected in an Algol light curve. Rather, there is a fairly flat maximum between the eclipses. Evidently this system had been mistakenly classified. Instead of two dissimilar stars in a semidetached mode, there are two similar stars in a detached configuration. The period, consequently, needs to be doubled. Three

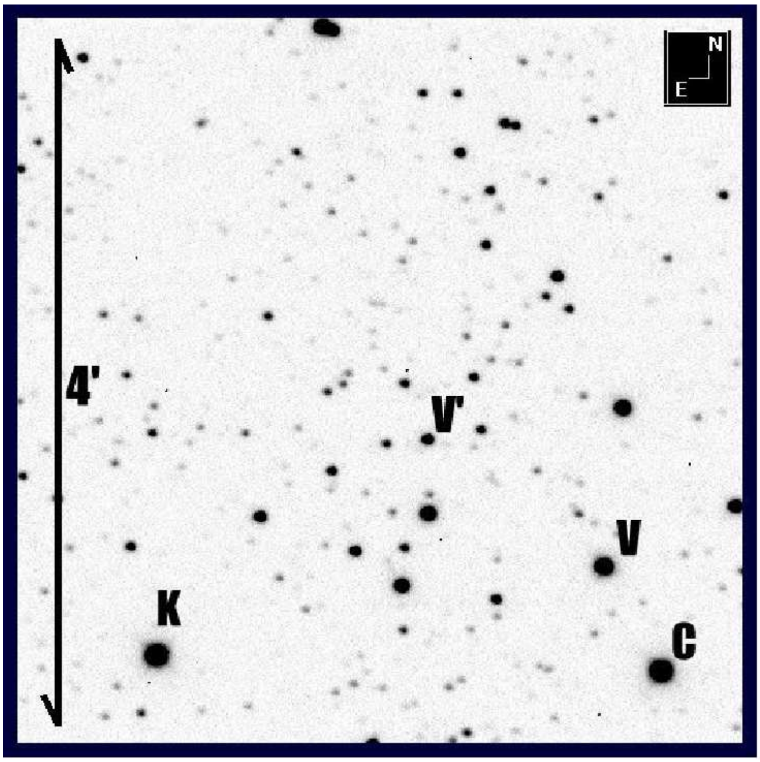

Figure 1. Finder Chart, V963 Cygni, comparison (C) and Check (K). V' is V965 Cygni.

mean epochs of minimum light were determined from $UBVRI$ timings of one primary and two secondary eclipses, HJD I = 2453207.7686 ± 0.003, HJD II = 2453209.8607 ± 0.0010, 2453211.9540 ± 0.0031. The following ephemeris reflects this finding:

$$\text{HJD Tmin I} = 2453209.8609 \pm 0.0007 + 1.39466785 \pm 0.00000016\text{d} \times \text{E}. \quad (2)$$

This was arrived at from 38 available times of minimum light (including ours) covering some 15000 orbits. Very recent timings seem to be forming a pattern, possible a negative parabola, but further observations are needed to verify the effect. All times of minimum light are shown in electronic Table 2 (available through the IBVS-website as `5786-t2.txt`). The next equation was calculated by the ephemeris option of the Wilson code (van Hamme and Wilson, 1998):

$$\text{HJD Tmin I} = 2453209.8585 \pm 0.0003 + 1.3945 \pm 0.0002\text{d} \times \text{E}.. \quad (3)$$

Standard magnitudes were calculated from our observations and 6 and 7 Landolt standard stars taken on July 20 and 24, respectively. They reveal that V963 Cyg is of spectral type F6.5 ± 1.0. Values for the comparison and check star are both F5 ± 0.5. Our standard magnitudes and color indices are given in electronic Table 3 (available through the IBVS-website as `5786-t3.txt`).

A $UBVRI$ synthetic solution was calculated. We first used Binary Maker 3.0 (Bradstreet, 2002) to provide an initial fit to each of the V, R, and I light curves. The fits were all detached. The main difficulty encountered in fitting the light curves were the irregularities in the out-of-eclipse portions, which evidently is due to several large spot regions. Thus, V963 Cyg has strong magnetic activity. The eclipse shoulders have somewhat different shapes in each effective wavelength. Particularly, the R curve is much different from the B curve in the shoulder of the secondary eclipse. This is believed be due to roving star magnetic spots arising from nonsynchronous rotation of each component. Our Binary Maker fits all gave a mass ratios of about 0.9.

Using our starting values, we proceeded to compute a simultaneous five color light curve solution with the updated Wilson Code (Wilson and Devinney, 1971; Wilson, 1990, 1994; Van Hamme and Wilson, 1998), which includes Kurucz stellar atmospheres, rather than black body, and a detailed reflection treatment along with 2-D limb darkening coefficients. The main mode of calculation is differential corrections. In addition to spot modeling, we tried adjusting the F parameter (non-synchronous rotation, Wilson 1979, Limber 1963), and third-light. It was found that the F parameter is the key to successfully modeling of the system. The system is evidently young and the stars are not yet gravitationally locked. This gives further evidence that the period is ~ 1.4d rather than ~ 0.7. An 0.7 day system in a nonsynchronous orbit would be exceptionally rare. Our solution indicates that the binary is a detached system with a mass ratio, $m_2/m_1 \sim 0.9$. The component temperature difference was only about 300 K. The solution reported here has 2 large spot regions. This indicates the magnetically active nature of this binary. The light curve solutions are given in electronic Table 4 (available through the IBVS-website as `5786-t4.txt`), and the calculated synthetic light curves are shown overlying the normalized light curve in Figure 2 and 3. The star surfaces are shown in Figure 4 (from Binary Maker). Due to the fact that the eclipses are partial, our model is preliminary. But a mass ratio near one is strongly suggested due to the deep and fairly equal eclipse depths. Radial velocity curves are needed for a complete solution. In this regard, we note here that errors given in the table are model dependent standard errors.

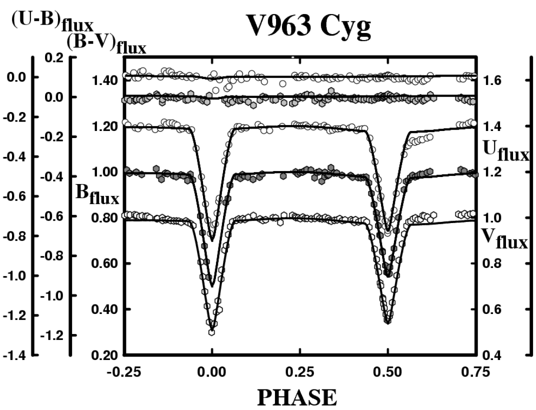

Figure 2. *UBVRI* Light curves compared with WD solution.

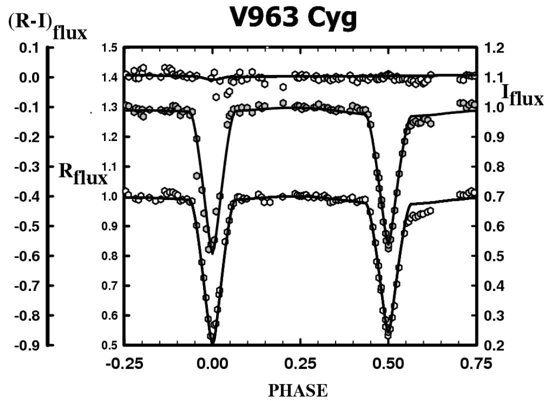

Figure 3. *UBVRI* Light curves compared with WD solution.

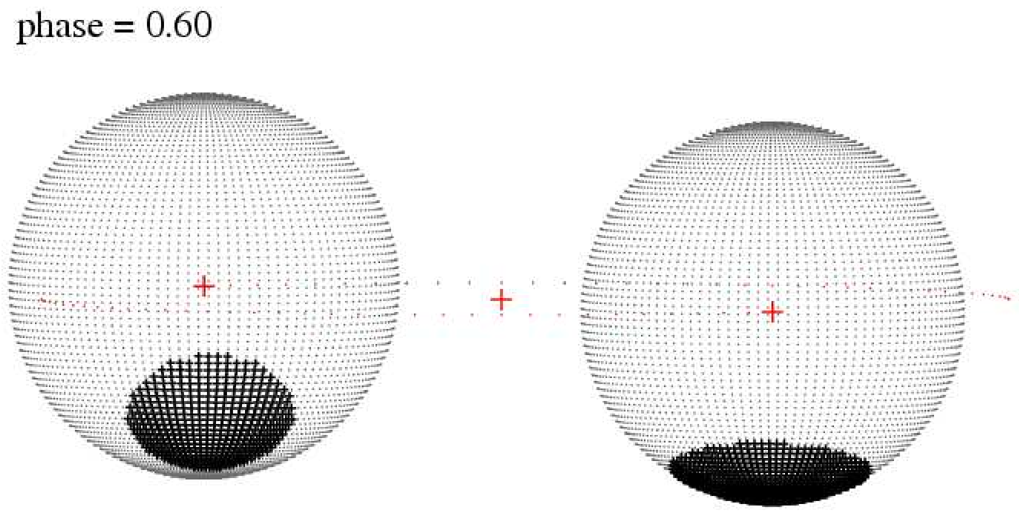

Figure 4. Star surfaces, V963 Cygni.

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