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V965 CYGNI, AN A AND F TYPE VERY HIGH FILL-OUT BINARY WITH STRONG MAGNETIC ACTIVITY?

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V965 Cygni [$\alpha(2000)=19^{\rm h}44^{\rm m}09\overset{\rm s}{.}3$, $\delta(2000)=+31^\circ 42' 37''$] was observed as a part of our continuing study of neglected interacting eclipsing binaries. It was discovered by Wachmann (1964) and identified as a W UMa star with a period of 0.64 days or possibly as an RR Lyrae type c with ~ 1 magnitude amplitude. He reported 7 times of minimum light. We recalculated his early ephemeris using our computer program using his original minima:

$$\text{HJD Tmin I} = 2435047.295\ (\pm 0.017) + 0.640575\ (\pm 0.000009)\ \text{d} \times \text{E}. \qquad (1)$$

In addition, four other times of minimum light have been published by Zejda, (2004), Hubscher, Paschke, Walter (2007) and by Hubscher, Paschke and Walter (2006). There have been no further references.

Our U, B, V, R, I light curves were taken with the Lowell 31 inch reflector in Flagstaff with the LN cooled CCD camera with a metachrome coated TEK 512 × 512 chip and standard BVR_cI_c filters on July 19-25, 2004. Our individual observations include 83 in U, 94 in B, 112 in V, 77 in R and 92 in I. A finding chart of V965 Cyg (V), the comparison star (C) (GSC 2656 3363) [$\alpha(2000) = 19^{\rm h}44^{\rm m}03\overset{\rm s}{.}64$, $\delta(2000) = 31^\circ 41' 13\overset{''}{.}25$], and the check star, (K) (GSC 2656 2055) [$\alpha(2000) = 19^{\rm h}44^{\rm m}16\overset{\rm s}{.}91$, $\delta(2000) = 31^\circ 41' 31\overset{''}{.}64$] are given in Figure 1. Our observations, Variable (V) minus Comparison (C) delta magnitudes are given in Table 1.

Standard magnitudes were determined from two nights of observations, July 20 and 24. V965 Cyg is found to have an apparent V magnitude range of $\sim 14.0 - 14.5$. Using a standard reddening line and a plot of $U - B$ vs. $B - V$ with a calibrated $U - B$ vs. $B - V$ main sequence plot (Cox, 2000) we determined a dereddened $(B - V)_0 \sim 0.07 \pm 0.02$. This is that of an A3-type main sequence star. From this we estimate the primary component to have a temperature of about 8725 K (Cox, 2000). The check and comp star are both of 11th magnitude and are of K4-K5V type. The standard magnitudes and color indices with uncertainties are given in Table 2.

We determined two times of minimum light from our present observations,

$$\text{HJD I} = 2453211.9135 \pm 0.0005 \text{ and HJD II} = 2453207.7440 \pm 0.0036.$$

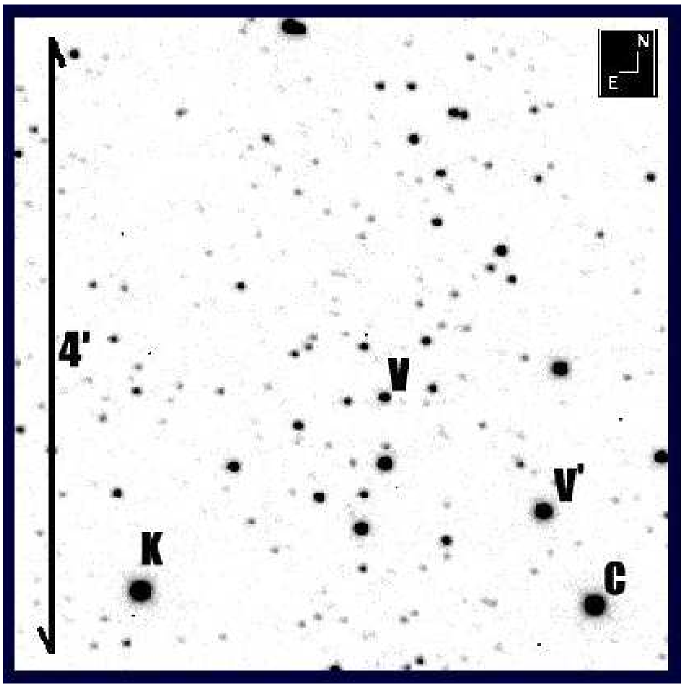

Figure 1. Finding Chart, V965 Cyg Variable (V), Comparison (C) and Check (K), V' is V963 Cyg.

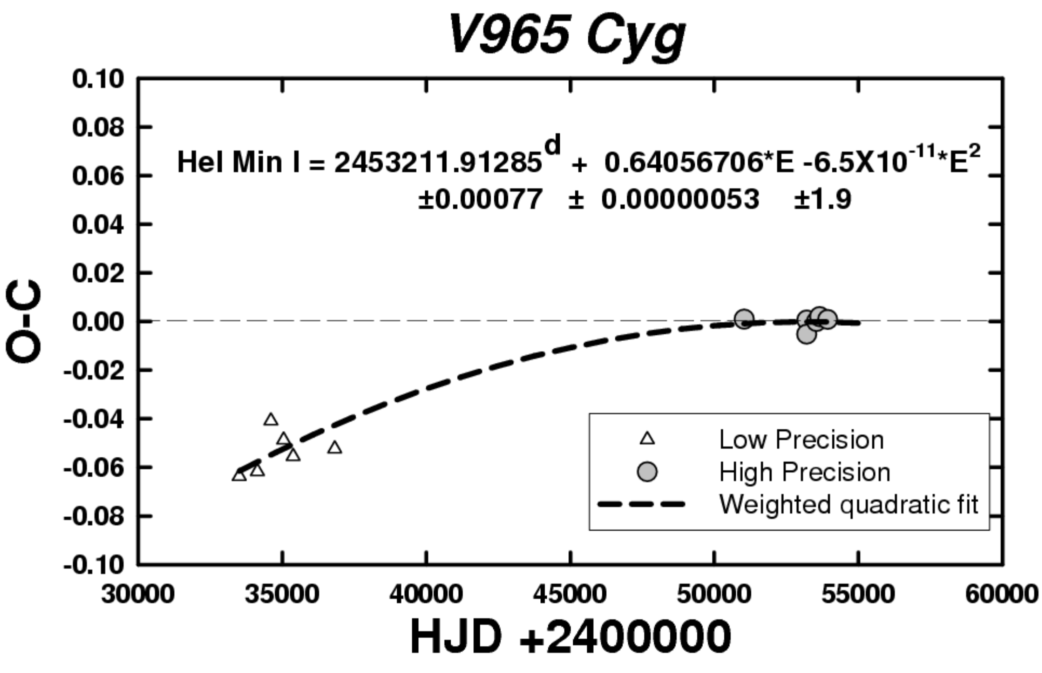

Figure 2. Quadratic fit overlying linear residuals from Equation 4.

The following ephemeris was calculated from all the available times of minimum light

$$\text{HJD Tmin I} = 2453211.9129\ (\pm 0.0009) + 0.64056889\ (\pm 0.00000010)\ \text{d} \times \text{E} \qquad (2)$$

A quadratic behavior is suggested by our timings. Our calculation gives:

$$\begin{array}{llll} \text{HJD Tmin I} & = 2453211.91285 & +0.64056706\ \text{d} \times \text{E} & -0.000000000065\ \text{d} \times \text{E}^2 \\ & \pm 0.00077 & \pm 0.00000053 & \pm 0.000000000019 \end{array} \qquad (3)$$

Since we only have twelve times of minimum light (one outlier removed), and there are only six precision points (weighted 10 times that of the earlier points), we believe the quadratic ephemeris is still tentative. However, the early points do supply a useful contribution to this determination. In fact the latest points, covering only a brief period suggest only a linear fit. Continued monitoring of this system will result in a true picture of its period behavior. All times of minimum light are shown in Table 3 along with the linear and the quadratic residuals. Figure 2 shows the quadratic residuals.

A *BVRI* synthetic light curve solution was undertaken. We first used Binary Maker 3.0 (Bradstreet, 2002) to explore the character of our light curves and determine initial fits to each of our *BVRI* light curves. Using the average starting values from these fits, we proceeded to compute a simultaneous five color light curve solution with the 2004 version of the Wilson Code (Wilson and Devinney, 1971; Wilson, 1990, 1994; Van Hamme and Wilson, 1998), which includes Kurucz atmospheres, rather than black body, and a detailed reflection treatment along with 2-D limb darkening coefficients. We explored a range of mass ratios to find the best fit.

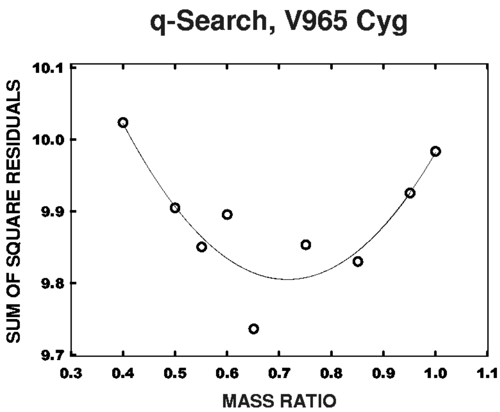

Figure 3. The q vs. sum of square residual plot of Mass Ratio Search for V965 Cyg.

Our first solution gave a contact binary with various characteristics which we will give below. The mass ratio was 0.55. Since the eclipses were partial (inclination 73 degrees), we conducted a q-search in parameter space to try to find the a better mass ratio. Our q-search is given in Figure 3. This curve is fairly shallow so the mass ratio is still not well determined. The lowest residual mass ratio was near 0.65. Taking this solution as a starting point, we determined a new solution allowing q to vary. The solution was essentially the same as that resulting from the q-search.

Our best solution and photometry reveals V965 Cyg as a hot, high fill-out contact binary (79%) (all our solutions gave high fill-outs) with a large polar spot region on the secondary (less massive) component. The spot would indicate V965 Cyg has strong magnetic activity. The high fill-out as well as its high rotation velocity would increase the convective activity. Also, with its high fill-out we would suspect that V965 Cyg will soon become unstable and coalesce into a FK Comae-type star. A decreasing period would help verify this scenario. Radial velocity curves are needed to give a solid determination of the mass ratio. The complete Wilson code solution is given in Table 4. The solution overlaying the *UBVRI* light curves are given in Figure 4, 5 and 6. Figure 7 shows the surface potential.

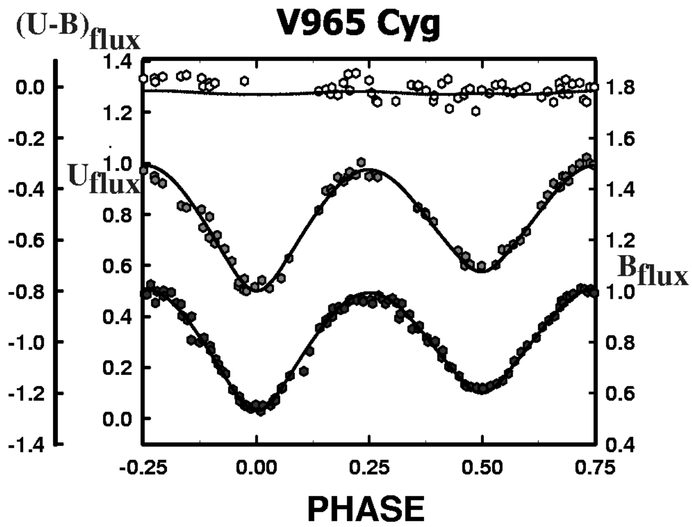

Figure 4. *UBVRI* light curves and $U-B$ color curve overlaid on the Synthetic Light Curve Model.

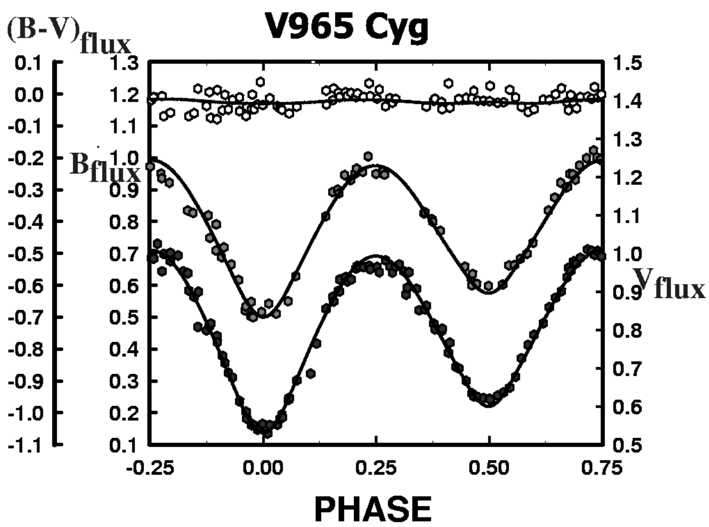

Figure 5. *UBVRI* light curves and $B-V$ color curves overlaid on the Synthetic Light Curve Model.

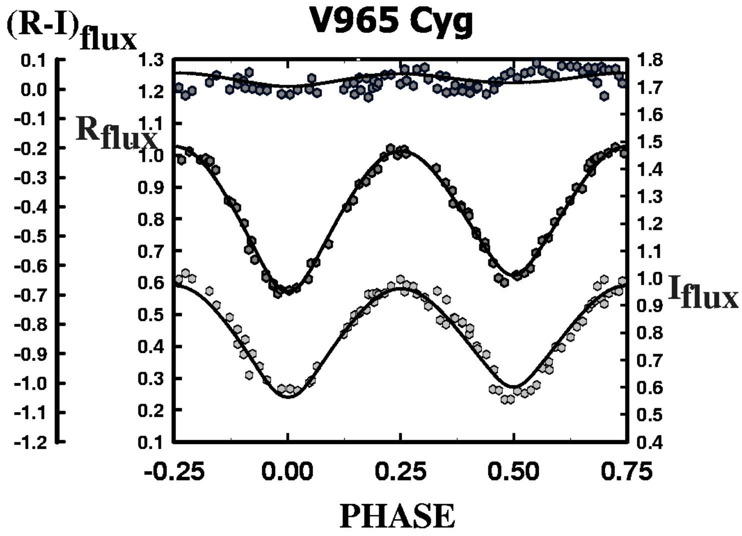

Figure 6. $UBVRI$ light curves and $R-I$ color curves overlaid on the Synthetic Light Curve Model.

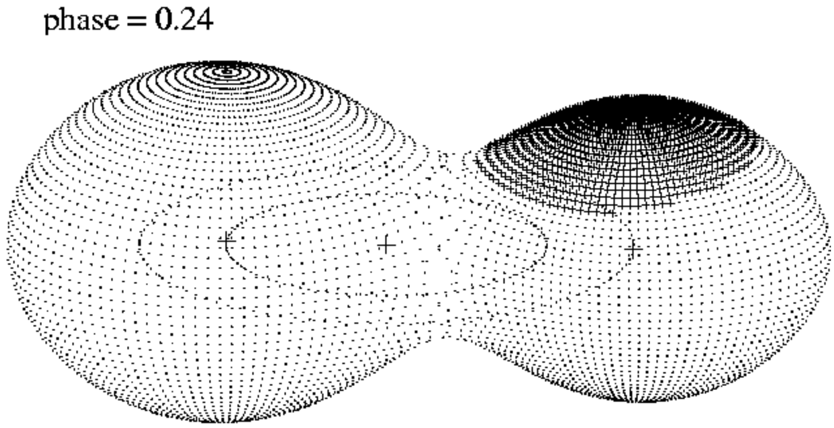

Figure 7. Stellar surface of V965 Cyg.

Table 4: Synthetic curve Parameters for V965 Cyg

Parameter	Best Fit Simultaneous solution
$\lambda_U, \lambda_B, \lambda_V, \lambda_R, \lambda_I$ (nm)	360, 440, 550, 640, 790
$x_{bol1,2}, y_{bol1,2}$	0.654, 0.654, 0.119, 0.119
$x_{1I,2I}, y_{1I,2I}$	0.446, 0.446, 0.209, 0.209
$x_{1R,2V}, y_{1V,2V}$	0.559, 0.559, 0.251, 0.251
$x_{1V,2B}, y_{1B,2B}$	0.660, 0.660, 0.281, 0.281
$x_{1B,2U}, y_{1U,2U}$	0.768, 0.768, 0.311, 0.311
g_1, g_2	1.00, 1.00
A_1, A_2	1.0, 1.0
inclination(°)	71.5±1.5
T_1, T_2 (K)	8725±300*, 7800±290**
Ω_1, Ω_2	2.867±0.022
q(m_2/m_1)	0.65±0.05
fill-out	76%
JD Zero	2453211.9149±0.0007
Period	0.64100±0.00015
$L_1/(L_1+L_2)_I$	0.64±0.05
$L_1/(L_1+L_2)_R$	0.65±0.06
$L_1/(L_1+L_2)_V$	0.67±0.06
$L_1/(L_1+L_2)_B$	0.69±0.07
$L_1/(L_1+L_2)_U$	0.69±0.07
r_1, r_2 (pole)	0.440±0.012, 0.370±0.015
r_1, r_2 (side)	0.478±0.013, 0.398±0.017
r_1, r_2 (back)	0.539±0.014, 0.484±0.026

∗ photometric + reddening estimate uncertainty.
∗∗ error calculated from Wilson code. As a photometric uncertainty, this should be about 200K.

Spot Parameters

STAR	Colatitude (°)	Longitude (°)	Spot Radius (°)	Temp. Factor
2	7.5±1.5	45.3±14.5	53±22	0.82±0.31

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