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TiO- AND V-BAND PHOTOMETRY OF THE PULSATING RED GIANT V CVn

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V CVn (HD 115898, HIP 65006) is a bright semi-regular red SRa variable star, located on the asymptotic red giant branch. V CVn is interesting because it has properties intermediate between classical Mira variables and Small Amplitude Red Variables (SARVs) as defined by Percy et al. (1996). The study of V CVn by Vetesnik and Papousek (1986) yields a mean photometric period near 192 days, with an average light amplitude of ≈ 1.5 to 2.0 magnitudes. From chiefly AAVSO visual estimates, the visual magnitude of V CVn typically varies from about +6.8 mag to +8.8 mag. The spectral type varies from M4 IIIe to M6 IIIe, and its spectrum is dominated by strong TiO bands (Boyle et al., 1986). Recently the parallax of V CVn has been improved by the Hipparcos satellite to yield a distance as 375 ± 125 pc. Because of the interesting characteristics of V CVn and the lack of detailed multi-wavelength photometry, the star was added to the ongoing program of photometry of cool giants and supergiants at Wasatonic Observatory and Villanova University Observatory. The results presented in this paper represent the first time the radius, luminosity and effective temperature of V CVn have been estimated using narrow to intermediate-band IR photometric techniques. Additionally, observations were made with a filter matched to the Johnson V-band filter at 550 nm.

Photometry was carried out using the Wing near-IR three filter system with filters centered on 719, 754, and 1024 nm, designated as A, B, and C, respectively (Wing, 1992; Morgan et al., 1997). TiO indices, (B−C)-IR color indices, and IR apparent magnitudes are calculated from the observations. The TiO index is calculated from the standardized A, B, and C magnitudes using the following equation adapted from Wing (1992):

$$\text{TiO Index} = \text{A}-\text{B} - 0.13(\text{B}-\text{C}) \qquad (1)$$

where B−C is the IR color index. As defined, a numerical increase in the TiO index corresponds to an increase in the TiO absorption at 719nm. In our calibrations of TiO index with spectral type, we find a linear correlation between the index and spectral type up to M8. For stars with spectral types later than M8, the A and B bandpasses become contaminated by molecular absorption bands such as VO and water vapor.

Using a large number of Wing standard stars (Wing, 1978), calibrations were done to establish the difference between observed C-band (1024 nm) magnitudes and calculated bolometric magnitudes using bolometric corrections from Novotny (1973). The observed 1024 nm magnitudes were then transformed to bolometric magnitudes (m_{bol}). Using the Hipparcos parallax, absolute bolometric magnitudes, and hence luminosities, were determined. Also, from Wing (1979) standard star data, IR color index - temperature calibrations were determined, enabling temperatures to be estimated from the observed IR color and TiO indices data. Knowing both luminosities and temperatures, radii were calculated throughout the pulsational cycle by using the equation:

$$(R_\star/R_\odot) = [(L_\star/L_\odot)/(T_\star/T_\odot)^4]^{0.5} \tag{2}$$

Mahler et al. (1997) and Morgan et al. (1997) provide additional details of the Wing 3-color near-IR system, which they used to estimate changing effective temperatures, luminosities, and radii of Mira and Betelgeuse, respectively. These same techniques were used to calculate T_{eff}, $L_\star/L_\odot$ and $R_\star/R_\odot$ for V CVn over its 191.8 day pulsational cycle.

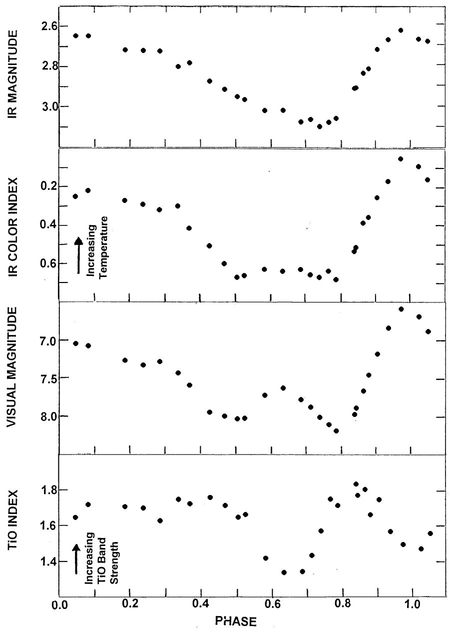

Figure 1. IR (1024 nm) magnitude, (B–C) color index, visual magnitude (550 nm), and TiO index of V CVn during the 1997 observing season

Differential photometry of V CVn was conducted during 1997 on 27 nights from JD 2450462 to JD 2450655 at Wasatonic Observatory. An uncooled SSP-3 Optec photometer, attached to a 20-cm Schmidt-Cassegrain telescope, was used to carry out the photometry. The detector was an uncooled silicon PIN-photodiode. The comparison star was HR 5067 (V = +5.88; B–V = +0.97; K0 III),and the check star was HD 120315 (η UMa, V = +1.86; B–V = −0.19; B3 V). The check star also served as the primary Wing IR standard star, from which all subsequent standardized comparison and variable star IR magnitudes were calculated. All data reductions accounted for atmospheric extinction effects and conversions of UT to HJD. The phases for V CVn were computed using the epoch given in the 1997 Astronomical Almanac, as follows:

$$T_{max} = \text{HJD } 2443929.00 + 191.^{d}89 \times E \tag{3}$$

Figure 1 shows the various photometric magnitudes and indices found for V CVn, plotted against pulsation phase. The C-band (1024 nm) magnitudes are plotted in the top panel. These data show a nearly smooth quasi-sinusoidal variation with a full amplitude of about δ C = 0.30 mag. Maximum and minimum brightness occur at phase 0.00 and 0.75, respectively. As discussed previously, the behavior of the C-band (1024 nm) magnitude is very similar to the apparent bolometric magnitude (m_{bol}) or the absolute bolometric magnitude (M_{bol}) when scaled with the Hipparcos parallax.

The IR (B−C) index is shown in the second panel in Figure 1. Note that this index varies in a similar manner to the C-band (1024 nm) magnitude. The B−C values vary from about +0.05 mag at IR maximum brightness to about +0.70 mag during IR light minimum. However, the most positive values of the (B−C) index occur over a broad, relatively flat minimum that extends from about phase 0.50 to 0.75. From previous (B−C)-T_{eff} calibrations, V CVn attains its maximum temperature of $T_{max} \approx 3200$ K near phase 0.00 and reaches a minimum value of $T_{min} \approx 2200$ K during the 0.50 to 0.75 phase interval. The absolute radius of the star can be found for each ($L_\star/L_\odot$;T_{eff}) data set from equation (2).

In this case, the star attains a maximum radius of $R_{max} \approx 400\ R_\odot$ near light minimum and shrinks to $R_{min} \approx 200\ R_\odot$ at maximum luminosity, when the star is hottest. Table 1 lists the estimated effective temperatures and, in solar units, radii and luminosities of V CVn at phases 0.00 and 0.75, corresponding to the C-band (1024 nm) maximum and minimum magnitudes, respectively.

Table 1. Temperatures, Radii, and Luminosities of V CVn at C-Band (1024nm) Maximum and Minimum Brightness

Phase	C-band mag	Temp.(K)	Radius ($R_\odot$)	Luminosity ($L_\odot$)
0.00	+2.65	3200	200	4600
0.75	+3.10	2200	400	3100

The observed V-band curve is shown in the third panel of Figure 1. It is similar to the light curves of V CVn by Magalhaes et al. (1986) and Kruszewski et al. (1968). Note the secondary maximum or "hump" centered at phase ≈ 0.65, which is also a feature in the Kruszewski light curve. As pointed out by Wing (1986), visual light curves for cool stars are strongly dependent on TiO blanketing. The hump in the V-band curve occurs at the same phase where the TiO index decreases, indicating a significant weakening of the TiO absorption. The calculated TiO index is shown in the bottom panel of Figure 1. From TiO - temperature and B−C color index calibrations, it was found that the numerical value of the TiO index gives a reliable measure of the TiO line strength out to values of approximately TiO ≈ 1.8.

Therefore, the nearly constant value of the TiO index of about +1.7 from phase 0.00 to phase 0.50 is near the limit where the TiO index is useful as a TiO band measure. However, the observed decrease of the TiO index to about +1.35 mag at phase 0.65 is very reliable and indicates TiO dissociation. This normally occurs with an increase in temperature. Note, however, that the temperature, as indicated by the (B−C) IR color-index curve (second panel, Figure 1) is relatively constant during this drop in the TiO index. Hence the TiO dissociation at this phase is not due to an increase in temperature, but probably results from other mechanisms. A possible explanation is that a shock wave propagated through the atmosphere, causing the TiO dissociation without producing a significant change in temperature. This could have led to the increase in brightness in the visual magnitude (the hump) at phase 0.65. As the shock dissipated, the TiO index increased from phase 0.65 to 0.80, indicating TiO recombination. This was accompanied by the decrease in the V-band light curve due to the TiO blanketing effect. As shown in the figure, from phase 0.85 to phase 0.00 the TiO index again drops as the star brightens in both the V-band and the C-band (1024 nm). These changes are accompanied by a decrease in the (B−C) index, indicative of increasing effective temperature and a dissociation of TiO. The decrease in the TiO line strength causes the drop in the TiO index itself. Data for all four panels of Figure 1 is tabulated in Table 2.

Continued photometry of V CVn is planned. In obtaining more data we hope to ascertain whether the phenomena observed during the 1996/97 observing season reoccurs. The

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Table 2. Plotted V CVn Data

HJD 2450+	Phase	Visual mag	C (1024 nm) mag	Color Index	TiO Index
462.766	0.046	+7.045	+2.649	+0.250	+1.645
469.775	0.082	+7.076	+2.650	+0.219	+1.717
489.626	0.186	+7.266	+2.719	+0.271	+1.707
499.926	0.238	+7.330	+2.723	+0.291	+1.699
508.593	0.285	+7.283	+2.725	+0.319	+1.627
518.604	0.337	+7.433	+2.802	+0.300	+1.748
524.647	0.369	+7.595	+2.783	+0.415	+1.723
535.643	0.426	+7.949	+2.874	+0.507	+1.760
543.553	0.468	+8.001	+2.915	+0.600	+1.714
550.577	0.504	+8.036	+2.951	+0.671	+1.647
554.575	0.525	+8.029	+2.965	+0.662	+1.663
565.576	0.582	+7.725	+3.019	+0.629	+1.418
575.694	0.634	+7.632	+3.018	+0.639	+1.339
585.647	0.686	+7.782	+3.074	+0.629	+1.343
590.590	0.713	+7.880	+3.062	+0.658	+1.433
595.634	0.739	+8.015	+3.097	+0.671	+1.570
600.606	0.765	+8.109	+3.076	+0.638	+1.750
604.607	0.786	+8.192	+3.057	+0.682	+1.714
614.598	0.838	+7.975	+2.908	+0.535	+1.835
615.600	0.843	+7.890	+2.905	+0.514	+1.771
619.610	0.864	+7.668	+2.833	+0.386	+1.805
622.609	0.879	+7.458	+2.811	+0.357	+1.661
627.608	0.905	+7.180	+2.715	+0.254	+1.747
633.602	0.937	+6.838	+2.667	+0.169	+1.567
640.598	0.974	+6.587	+2.670	+0.051	+1.495
650.586	0.025	+6.688	+2.664	+0.091	+1.470
655.573	0.051	+6.882	+2.674	+0.160	+1.556

References:

Nautical Almanac Office, USNO., H.M. Nautical Almanac Office, Royal Greenwich Observatory, Astronomical Almanac, 1997, U.S. Government Printing Office, p. H71

Boyle, R.P., Aspin, C., Coyne,G.V., McLean, I.S., 1986, *Astron. Astrophys.*, **164**, 310

Kruszewski, A., Gehrels, T., Serkowski, K., 1968, *AJ.*, **73**, 677

Magalhaes, A.M., Coyne, G.V., Benedetti, E.K., 1986, *AJ.*, **91**, 919

Mahler, T., Wasatonic, R.P., Guinan, E.F. 1997, *IBVS*, No. 4500

Morgan, N., Wasatonic, R.P., Guinan, E.F. 1997, *IBVS*, No. 4499

Percy, J.R., Desjardins, A., Yu, L., Landis, H.J., 1996, *PASP*, **108**, 139

Novotny, E., 1973, Introduction to Stellar Interiors, (Oxford University Press), p.11

Vetesnik, M., Papousek, J., 1986, Studies on the Light Changes of Semiregular Red Variable Stars - 1. University of J.E. Purkyne, Czechoslovakia

Wing, R.F., 1978 in Spectral Classification and Color Temperatures, for 280 Bright Stars in the Range K4 - M8, Astronomy Department, Ohio State University

Wing, R.F., 1979, Dudley Obs. Report 14, A.G. Davis Philip, ed.

Wing, R.F., 1986 in The Study of Variable Stars Using Small Telescopes, ed. J.R. Percy, Cambridge University Press, Cambridge, England, p. 131

Wing, R.F., 1992, *JAAVSO*, **21**, 42