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PHOTOELECTRIC OBSERVATIONS OF VV PUPPIS

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I. Introduction and Observations.

The variability of VV Puppis was discovered by Van Gent (1931), who found that the period of variation is 100 minutes. Subsequent photometric observations by various observers indicated that the behavior of the star is quite complex, but it was supposed that the object was an ultra-short period RR Lyrae variable; a summary of these photometric investigations is given by Herbig (1960). In 1960, spectroscopic observations by Herbig (1960) indicated that instead of being a pulsating variable, the object is actually an ultra short-period binary system, perhaps similar to the UX UMa class of binaries. Accurate photoelectric observations of VV Pup are clearly of importance to permit a more detailed comparison of this system with other short-period binaries.

Photometric observations were obtained on three nights in 1964, February 10, March 15, and March 20 (UT), using the 120-inch reflector. The photometer employed a 1P21 photomultiplier tube, refrigerated with dry ice, and the following filters: Yellow, Corning 3384, standard optical thickness; Blue, 1 mm Schott BG 12 plus 2 mm Schott GG13; Ultraviolet, Corning 9863, standard optical thickness. On February 10 and March 15, the measures were made using a focal plane diaphragm 13″ in diameter; on March 20 a diaphragm 11″ in diameter was used. Owing to the short period of VV Pup, continuous observations were made, using an offset eyepiece to keep the star centered in the diaphragm. Sky measurements were made each 5 minutes during continuous monitoring in one color, and before or after each deflection during the three-color measurements. No comparison stars were observed during the observations of the variable. Before and after the measures of VV Pup, observations of stars having known magnitudes and colors on the U, B, V system of Johnson and Morgan (1953) were obtained, and these measurements were used to determine the extinction and to convert the observations of VV Pup to the U, B, V system. The observations are listed in Tables 1—3, and are plotted in Figures 1—3.

The observed times of maximum light have been used to derive the following improved elements for the light-variation:

$$\text{Max} = \text{JD } 2427889.6474 + 0\overset{d}{.}0697468256\, E.$$

These elements were used in computing the phases of the observations in Tables 1—3 and Figures 1—3. The epoch used in the above elements is that given by Thackeray, et al. (1950), and the improved value of the period is only very slightly different from that given by him. This result probably tends to confirm the constancy of the period reported by the earlier observers (see Herbig 1960), but it must be kept in mind that phase shifts in the time of maximum light of up to 0.1P have been reported (Herbig 1960), so that the apparent agreement with the older elements could be fortuitous; a large number of maxima should be observed to derive a definitive set of elements.

The light-curves indicate that in yellow light, the system is constant within 0.1 mag. from phase 0.2P to 0.7P, just one-half of the period. In blue and ultraviolet light, the brightness decreases by about 0.1 mag. from 0.2P to 0.7P if the average of the first and second cycles observed on March 20 is used. During the first cycle on this night, the brightness in blue and ultraviolet remained constant from 0.2P to 0.4P, decreasing to a minimum at 0.7P there-

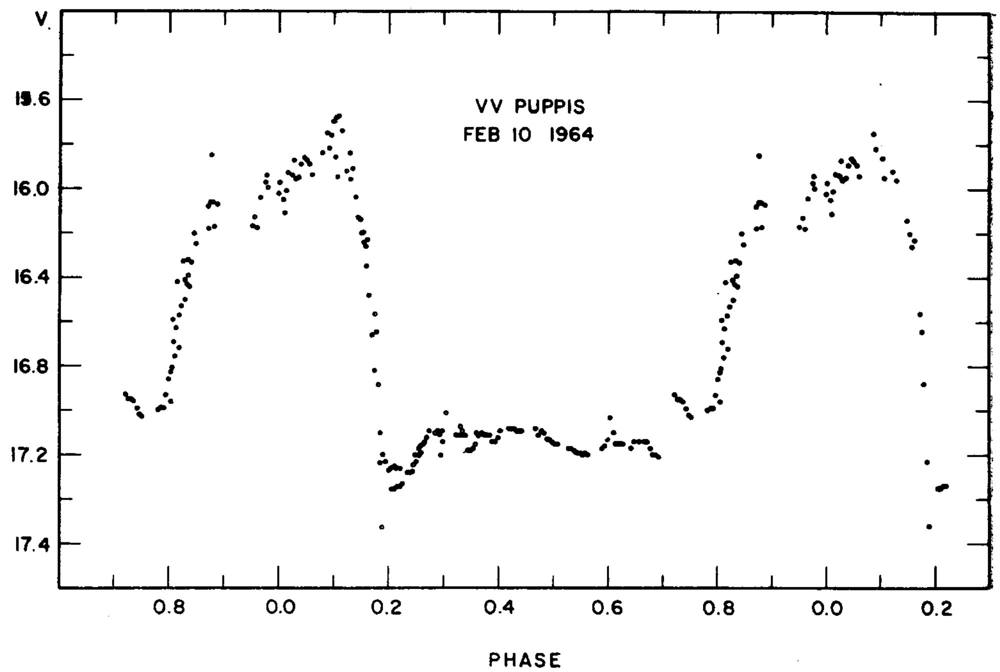

Fig. 1. Photoelectric observations of VV Pup on February 10, 1964 in yellow light. Circles represent observations shifted one cycle to the left. Phases computed from the elements given in the text.

after. The initial rise in brightness after 0.7P is nearly as rapid as the decline before 0.2P. However, near the top of the rise differences in the shape of maximum occur. Symmetric maxima and maxima with a sharp peak both before and after the midpoint of the maximum at phase 0.0P have been observed. The light-curves also show that the height of the maximum decreases with decreasing wavelength and increases with increasing brightness of the system at minimum light. The heights of maximum, measured from the light level at 0.65P, together with the date of observation and the minimum brightness of the system in yellow (V) light, are listed in Table 4. The width of the maximum appears to be the same in yellow and blue light; the number of observations in ultraviolet light is too small to make a definitive measurement possible. Color measurements are difficult owing to the rapid variations in brightness of the system. However, by using smoothed curves and interpolat-

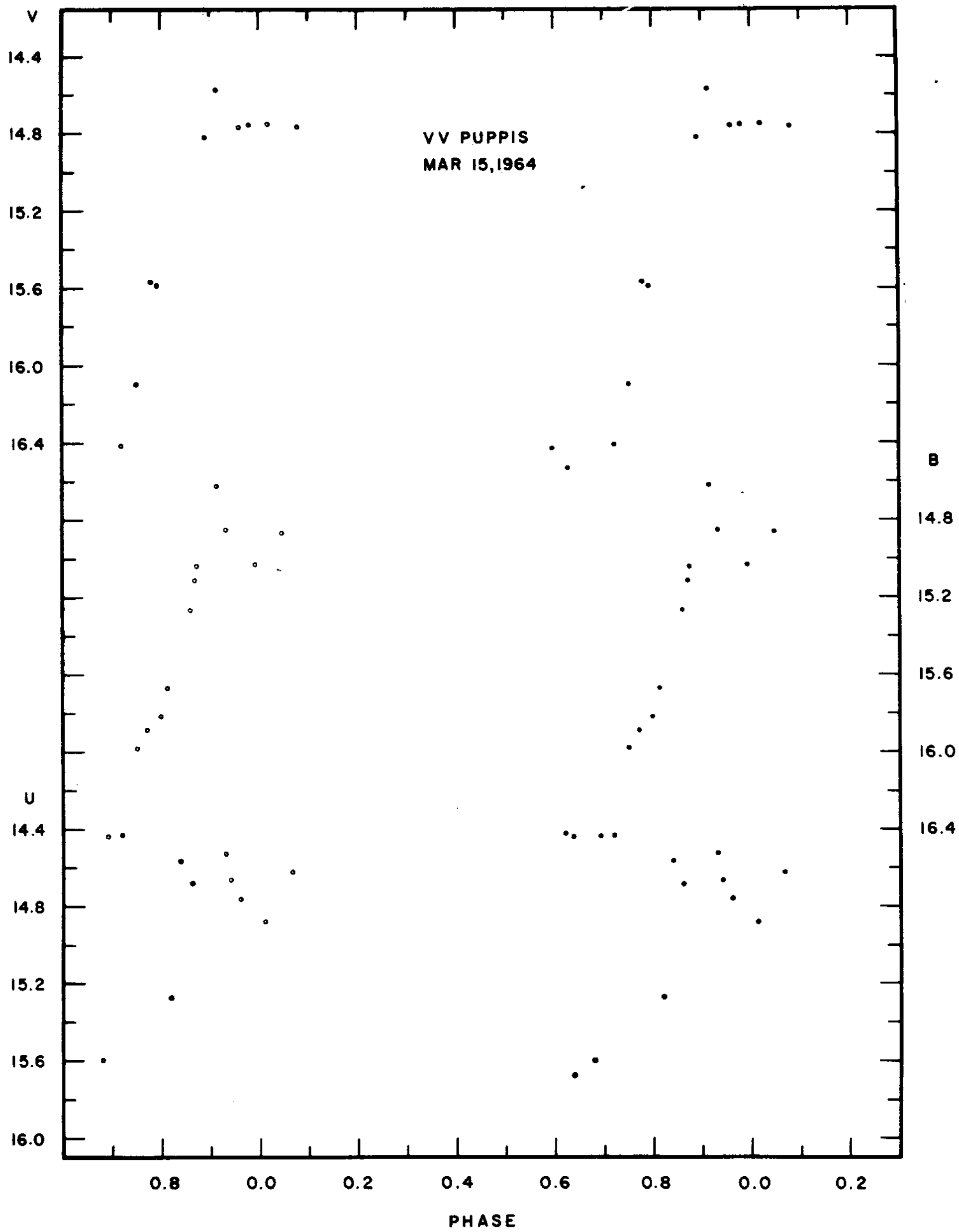

Fig. 2. Photoelectric observations of VV Pup on March 15, 1964, in yellow, blue, and ultraviolet light. Symbols and phases as in Figure 1.

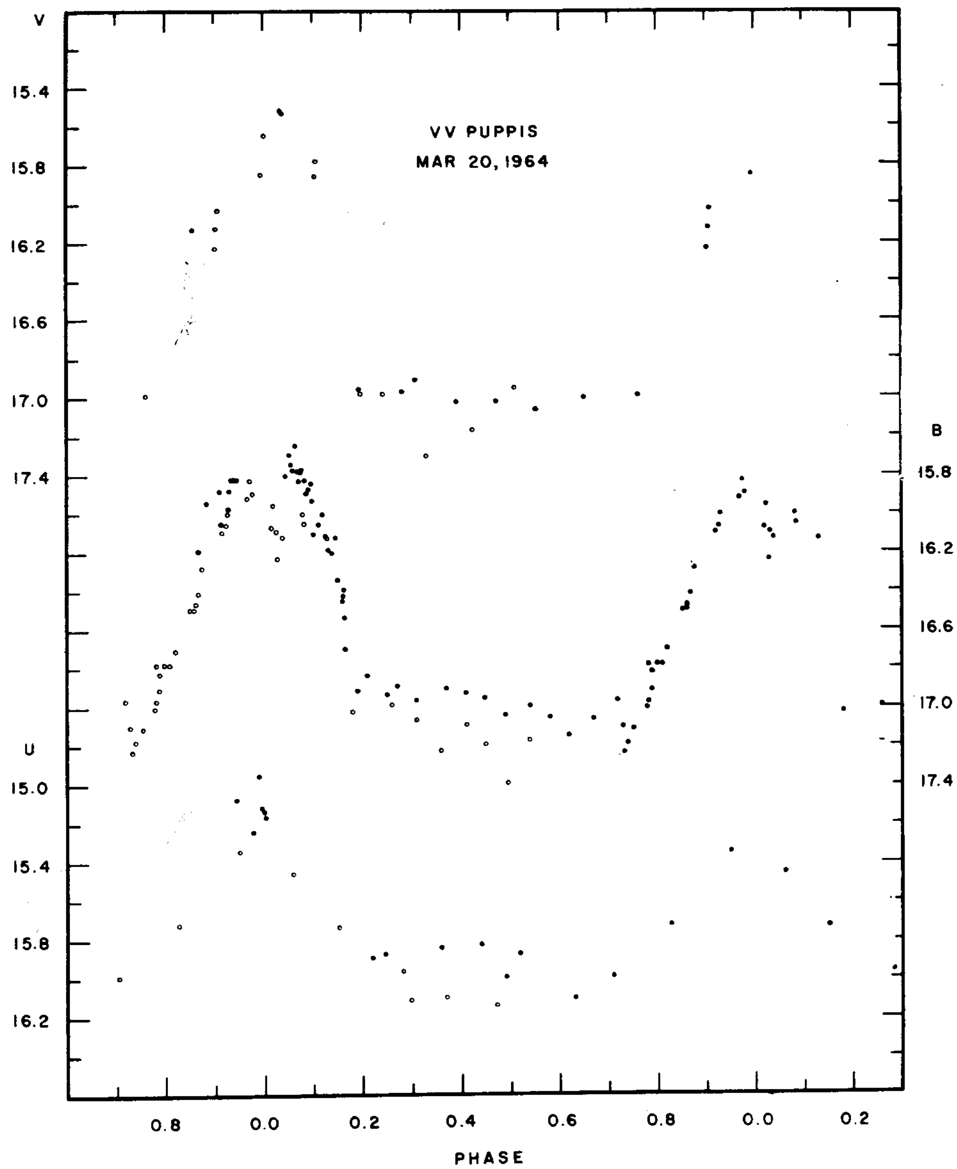

Fig. 3. Photoelectric observations of VV Pup on March 20, 1964, in yellow, blue, and ultraviolet light. Symbols and phases as in Figure 1.

ing between successive observations, the approximate values of the colors at different phases and for different values of the V magnitude at minimum have been derived and are listed in Table 5. The color variations, of course, reflect the shape of the light curve as a function of wavelength and magnitude at minimum discussed above. Thus, Table 5 shows that $B-V$ increases slightly between phases 0.2P and 0.7P while $U-B$ remains constant during this interval. Both $B-V$ and $U-B$ become appreciably redder during maximum due to the decrease in amplitude of the maximum with wavelength.

The light-curves show the existence of rapid, intrinsic variations throughout the 100-minute cycle. The amplitude and frequency of these variations appears to be a maximum during maximum light. Rapid fluctuations during maximum have been noted previously (Thackeray et al. 1950; Oosterhoff and Thackeray 1960). These variations have been studied on February 10 in yellow light, and on March 20 in blue light between phases 0.05P and 0.17P, in order to determine whether rapid periodic variations occur similar to those found previously in DQ Her (Walker 1956, 1958, 1961). The detection of a rapid, periodic variation with an amplitude of the order of 0.05 mag. would only be possible during maximum light; at minimum, such a variation would be obscured by the noise owing to the faintness of the star. A number of maxima and minima were found during maximum light. These were measured and are identified in Tables 1 and 2 by a plus sign for a maximum and a minus sign for a minimum. Attempts to represent them with a uniform period were only partially successful. Most, but not all, of the variations could be represented by a period of about 67 seconds. Departures from that period could result from disturbances in the times of maximum and minimum due to the poor signal-to-noise ratio even during maximum light, but it is also entirely possible that the apparent periodic occurrence of these maxima and minima was only fortuitous. The observations suggest, however, that a periodic variation *may* be detectable in this object, and it is clearly of importance to obtain additional observations in order to determine if this variation really exists. Another feature of the light-curve, repeated during the two successive cycles observed on February 10, is a small minimum which occurred at phase 0.225P. Apart from these variations, the intrinsic variability of the system appears to be completely random.

Table 1
VISUAL OBSERVATIONS

Helioc JD 2438000+	Helioc Phase	V Mag.	Helioc JD 2438000+	Helioc Phase	V Mag.
435.8612	.0795	15.84	435.8886	.4724	17.11
.8623	.0953	15.76	.8890	.4781	17.09
.8626	.0996	15.70	.8893	.4824	17.10
.8629	.1039	15.68	.8897	.4882	17.13
.8633	.1097	15.67	.8900	.4925	17.13
.8636	.1140	15.74	.8904	.4982	17.14
.8647	.1297	15.84	.8907	.5025	17.15
.8650	.1340	15.91	.8911	.5082	17.15
.8654	.1398	16.04	.8925	.5283	17.17
.8657	.1441	16.13	.8928	.5326	17.17
.8661	.1498	16.20	.8932	.5383	17.18
.8664	.1541	16.24	.8935	.5426	17.19
.8668	.1598	16.35	.8939	.5484	17.19
.8671	.1641	16.48	.8942	.5527	17.20
.8675	.1699	16.66	.8946	.5584	17.19
.8678	.1742	16.82	.8949	.5627	17.20
.8685	.1842	17.10	.8967	.5885	17.17
.8689	.1899	17.20	.8970	.5928	17.16
.8692	.1942	17.23	.8974	.5986	17.13
.8696	.2000	17.27	.8977	.6029	17.03
.8699	.2043	17.26	.8981	.6086	17.10
.8703	.2100	17.25	.8984	.6129	17.15
.8706	.2143	17.26	.8987	.6172	17.15
.8710	.2201	17.26	.8990	.6215	17.15
.8720	.2344	17.28	.8994	.6272	17.15
.8724	.2401	17.28	.9004	.6416	17.17
.8727	.2444	17.27	.9008	.6473	17.14
.8731	.2502	17.23	.9015	.6573	17.14
.8734	.2545	17.20	.9022	.6674	17.14
.8737	.2588	17.19	.9025	.6717	17.14
.8740	.2631	17.15	.9029	.6774	17.17
.8744	.2688	17.12	.9032	.6817	17.20
.8747	.2731	17.09	.9036	.6874	17.20
.8761	.2932	17.11	.9039	.6918	17.21
.8765	.2989	17.14	.9060	.7219	16.93
.8782	.3233	17.11	.9064	.7276	16.95
.8786	.3290	17.11	.9067	.7319	16.95
.8789	.3333	17.11	.9071	.7376	16.96
.8793	.3391	17.11	.9074	.7419	16.99
.8807	.3591	17.10	.9078	.7477	17.02
.8810	.3634	17.11	.9081	.7520	17.03
.8814	.3692	17.10	.9102	.7821	17.00
.8817	.3735	17.11	.9106	.7878	16.99
.8821	.3792	17.11	.9109	.7921	16.99
.8824	.3835	17.11	.9112	.7964	16.93
.8828	.3892	17.14	.9115	.8007	16.86
.8831	.3935	17.14	.9117	.8036	16.83
.8835	.3993	17.12	.9118	.8050	16.96
.8838	.4036	17.09	.9119	.8065	16.81
.8849	.4193	17.08	.9120	.8079	16.59+
.8852	.4236	17.08	.9121	.8093	16.69
.8856	.4294	17.08	.9122	.8108	16.76—
.8859	.4337	17.09	.9123	.8122	16.63
.8862	.4380	17.09	.9125	.8151	16.42+
.8865	.4423	17.09	.9127	.8179	16.57
.8883	.4681	17.08	.9127	.8179	16.72—

Table 1 (Continued)

Helioc JD 2438000+	Helioc Phase	V Mag.	Helioc JD 2438000+	Helioc Phase	V Mag.
435.9130	.8222	16.53	435.9404	.2151	17.34
.9132	.8251	16.33+	.9407	.2194	17.33
.9134	.8280	16.41	.9411	.2251	17.33
.9135	.8294	16.50—	.9425	.2452	17.24
.9136	.8308	16.43	.9428	.2495	17.20
.9138	.8337	16.32+	.9432	.2552	17.17
.9139	.8351	16.39	.9435	.2595	17.16
.9140	.8366	16.44—	.9439	.2653	17.14
.9143	.8409	16.33	.9453	.2853	17.10
.9146	.8452	16.20+	.9456	.2896	17.09
.9148	.8480	16.25	.9460	.2954	17.20
.9164	.8710	16.08	.9463	.2997	17.09
.9165	.8724	16.18—	.9467	.3054	17.01
.9167	.8753	16.06	.9484	.3298	17.07
.9168	.8767	15.85+	.9487	.3341	17.09
.9170	.8796	16.06	.9490	.3384	17.11
.9172	.8824	16.17—	.9494	.3441	17.18
.9175	.8868	16.07	.9497	.3484	17.18
.9220	.9513	16.17	.9501	.3542	17.17
.9224	.9570	16.13	.9504	.3584	17.15
.9227	.9613	16.18	469.7941	.5949	16.43
.9231	.9670	16.04	.7948	.6049	16.53
.9234	.9713	15.98	.8031	.7239	16.41
.9237	.9756	15.94	.8047	.7468	16.10
.9251	.9957	15.98	.8069	.7784	15.57
.9254	.0000	16.02	.8076	.7884	15.59
.9258	.0058	15.97	.8149	.8931	14.82
.9259	.0072	16.05	.8159	.9074	14.57
.9261	.0101	16.11	.8194	.9576	14.77
.9264	.0144	16.01	.8208	.9777	14.76
.9265	.0158	15.93	.8239	.0221	14.75
.9270	.0230	15.94	.8281	.0823	14.76
.9272	.0258	15.87	474.6940	.8475	16.29
.9275	.0301	15.96	.6948	.8590	16.13
.9279	.0359	15.95	.7071	.0354	15.52
.9282	.0402	15.89	.7074	.0397	15.54
.9286	.0459	15.86	.7184	.1974	16.96
.9289	.0502	15.87	.7242	.2805	16.97
.9293	.0559	15.89	.7261	.3078	16.91
.9296	.0602	15.94	.7320	.3924	17.02
.9315	.0875	15.75	.7375	.4712	17.02
.9317	.0903	15.82	.7435	.5572	17.07
.9326	.1032	15.86	.7502	.6533	17.00
.9328	.1061	15.95	.7608	.7608	16.99
.9339	.1219	15.92	.7675	.9013	16.28
.9344	.1291	15.96	.7678	.9056	16.16
.9348	.1491	16.14	.7680	.9085	16.07
.9361	.1534	16.20	.7742	.9974	15.85—
.9364	.1577	16.26	.7746	.0031	15.65+
.9367	.1620	16.23	.7817	.1049	15.86
.9374	.1721	16.56	.7820	.1092	15.78—
.9376	.1749	16.64	.7883	.1996	16.99
.9379	.1792	16.88	.7912	.2411	16.98
.9383	.1850	17.23	.7978	.3358	17.30
.9386	.1893	17.52	.8041	.4261	17.17
.9397	.2050	17.35	.8102	.5136	16.95
.9400	.2093	17.35			

Table 2

BLUE OBSERVATIONS

Helioc JD 2438000+	Helioc Phase	B Mag.	Helioc JD 2438000+	Helioc Phase	B Mag.
469.7962	.6250	16.42	474.7194	.2117	16.83
.7969	.6350	16.44	.7223	.2533	16.93
.8009	.6924	16.44	.7236	.2719	16.89
.8026	.7167	16.42	.7261	.3078	16.97
.8047	.7468	15.98	.7307	.3737	16.90
.8066	.7741	15.89	.7334	.4124	16.92
.8081	.7956	15.82	.7358	.4468	16.95
.8094	.8142	15.67	.7390	.4927	17.04
.8125	.8587	15.27	.7423	.5400	16.99
.8132	.8687	15.11	.7452	.5816	17.05
.8135	.8730	15.04	.7482	.6246	17.14
.8164	.9146	14.62	.7515	.6719	17.06
.8176	.9318	14.85	.7550	.7221	16.96
.8220	.9949	15.03	.7553	.7264	17.10
.8257	.0479	14.86	.7557	.7322	17.23
474.6955	.8690	16.19	.7567	.7465	17.18
.6966	.8848	15.94	.7570	.7508	17.11
.6984	.9106	15.88	.7589	.7780	17.01
.6987	.9149	16.05	.7591	.7809	16.97
.6996	.9278	15.97	.7594	.7852	16.78
.6998	.9307	15.88	.7598	.7909	16.91
.7001	.9350	15.82	.7601	.7952	16.82
.7005	.9407	15.82	.7605	.8010	16.78
.7008	.9450	15.82	.7615	.8153	16.78
.7081	.0497	15.80	.7619	.8211	16.70
.7084	.0540	15.69+	.7643	.8555	16.51
.7086	.0569	15.74	.7646	.8598	16.49
.7088	.0597	15.77—	.7650	.8655	16.47
.7091	.0640	15.71	.7653	.8698	16.41
.7092	.0655	15.64+	.7666	.8884	16.28
.7094	.0683	15.78	.7690	.9229	16.09
.7095	.0698	15.83—	.7692	.9257	16.06
.7099	.0755	15.78	.7695	.9300	16.00
.7100	.0769	15.77+	.7723	.9702	15.92
.7103	.0812	15.82	.7726	.9745	15.83
.7106	.0855	15.89—	.7730	.9802	15.89
.7109	.0898	15.87	.7759	.0218	16.07
.7114	.0970	15.84+	.7761	.0246	15.95+
.7116	.0999	15.93	.7764	.0289	16.09
.7121	.1070	16.10—	.7765	.0304	16.24—
.7127	.1156	16.05	.7769	.0361	16.12
.7130	.1199	16.00+	.7798	.0791	16.01
.7134	.1257	16.11	.7803	.0849	16.05
.7139	.1329	16.18—	.7835	.1307	16.13
.7143	.1386	16.20	.7869	.1795	17.02
.7150	.1486	16.12+	.7928	.2641	16.99
.7154	.1544	16.34	.7963	.3143	17.06
.7157	.1586	16.45—	.7993	.3573	17.22
.7157	.1586	16.42	.8028	.4075	17.09
.7158	.1601	16.39+	.8057	.4490	17.19
.7161	.1644	16.53	.8089	.4949	17.39
.7163	.1673	16.70	.8118	.5365	17.17
.7179	.1902	16.91			

Table 3

ULTRAVIOLET OBSERVATIONS

Helioc JD 2438000+	Helioc Phase	U Mag.	Helioc JD 2438000+	Helioc Phase	U Mag.
469.7975	.6436	15.67	474.7218	.2461	15.87
.8001	.6809	15.60	.7291	.3508	15.84
.8098	.8200	15.27	.7352	.4382	15.82
.8114	.8429	14.56	.7390	.4927	15.99
.8125	.8587	14.68	.7412	.5243	15.87
.8176	.9318	14.52	.7473	.6117	16.10
.8181	.9390	14.66	.7544	.7135	15.99
.8189	.9504	14.76	.7629	.8354	15.72
.8232	.0121	14.88	.7709	.9501	15.34
.8268	.0637	14.62	.7785	.0591	15.44
474.7022	.9561	15.07	.7851	.1537	15.73
.7032	.9794	15.24	.7942	.2842	15.96
.7037	.9866	14.95	.7945	.2884	16.13
.7043	.9952	15.11	.7948	.2928	16.21
.7046	.9995	15.13	.8007	.3774	16.10
.7050	.0052	15.16	.8070	.4677	16.14
.7205	.2275	15.89			

Table 4

HEIGHTS OF MAXIMA OF VV PUP

Date UT	V_{min} (mag)	Height of Maximum (mag)		
		V	B	U
1964				
Feb. 10	17.1	1.4	—	—
Mar. 15	16.4	1.8	1.6	1.0
Mar. 20	17.0	1.4	1.2	0.9

Table 5

COLORS OF VV PUP

Phase	$B-V$		$U-B$	
	$V^{*}_{min} = 16.4$	$V^{**}_{min} = 17.0$	$V^{*}_{min} = 16.4$	$V^{**}_{min} = 17.0$
0.2	—	0.00	—	−1.1
0.5	—	+0.05	—	−1.1
0.7	+0.05	+0.05	−0.8	−1.1
1.0	+0.27	+0.30	−0.02	−0.8

* March 15, 1964
** March 20, 1964

II. Discussion.

In color, shortness of period, and the occurrence of rapid intrinsic variability, VV Pup resembles the stars of the "UX UMa" class, which include: UX UMa (Johnson, Perkins, and Hiltner 1954; Walker and Herbig 1954; Krzeminski and Walker 1963), DQ Her (Walker 1956, 1958, 1961), RW Tri (Walker 1963a), T Aur (Walker 1963b), WZ Sge (Krzeminski 1962), and U Gem (Kraft 1962, Mumford 1962, 1964). VV Pup also resembles these systems in having, in blue and ultraviolet light, a shallow minimum near 0.7P. The light-curve of VV Pup is particularly similar to that of U Gem, as noted by Mumford (1964). This similarity is made more striking by the present observations. In both systems "minimum" light lasts just 0.55 of the period, with some decrease in brightness between phases 0.2 and 0.7 in blue and ultraviolet light (taking zero phase at maximum light). In both cases, the height of maximum decreases with decreasing wavelength, although the wavelength dependence is smaller in U Gem than in VV Pup, the heights of maximum ranging from 0.60 mag. in yellow and blue light to 0.50 mag. in ultraviolet light. The colors of the two systems are also somewhat similar. At 0.7P, the colors of U Gem are $B-V = +0.5$, $U-B = -0{,}7$, and at 0.0P (maximum light), $B-V = +0.35$, $U-B = -0{,}55$ (Mumford 1964).

The light and velocity variations of VV Pup have been explained by Herbig (1960) in terms of a model in which the brighter star is the larger and has a bright spot on its surface displaced about 45° from the subsecondary point on the preceding hemisphere of the star. In U Gem, the fact that an eclipse is observed about 0.15P after maximum light suggests that in this system the brighter object consists of a small, hot star surrounded by some sort of extended atmosphere or cloud which possesses a markedly non-uniform surface brightness. The present observations suggest that the brighter star in VV Pup may have a similar structure. As mentioned in Section I, small minima in the light curve occurred at phase 0.225P during two successive cycles on February 10. These minima were not observed on March 20. Owing to the fact that measures in three colors were made, the coverage of this particular part of the curve is not intensive. Nevertheless, it would seem that sufficient observations were obtained that some indication of the minima should be visible had it existed. Despite the absence of the minima of March 20, it appears possible that these minima could represent the partial eclipse of a small hot star as in U Gem. The occasional absence of the eclipse might be explained by veiling of the star by the surrounding material. It is interesting to note that the minima on February 10 are slightly asymmetric, the actual point of minimum light lying near 0.215P. The end of the minimum occurs at 0.270P. If we suppose that mid-eclipse occurs at 0.215P, then first contact should occur at 0.155P. Examining the light-curves, we find that just at this phase, on February 10, the slope of the descent from maximum light increases; for phases less than 0.155P, the slope matches the reflected slope of the rise to maximum light. The same phenomenon can be observed in the light-curve of March 20, except that on this night the change in slope occurs at phase 0.145P. The existence of this effect would appear to strengthen somewhat the supposition that the minima at 0.225P (or 0.215P) represent eclipses even though the spectroscopic observations (Herbig 1960) predict that mid-eclipse should come at 0.29P. Clearly, further observations to determine whether this minimum is an eclipse, or was only a transitory feature lasting for only two or more cycles on February 10, are highly desirable.

It is a pleasure to thank Dr. G. Chincarini and Mr. R. Freedman for their assistance in the reduction of these observations.

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