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A PHOTOMETRIC STUDY OF SW ANDROMEDAE

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Photometric ($uvby\beta$) observations of the strong-line RR Lyrae variable SW And are described. The photometry suggests that the star is reddened by $E(b-y) = 0^m036$. Intrinsic $(b-y)$ and c_1 values are used to derive the variations in T_{eff} and log g. The mean values are $\langle T_{eff}\rangle = 6680$ K and $\langle \log g\rangle = 2.9$. Wesselink's method is used to derive a radius of $R/R_\odot = 4.45$. The radius, $\langle T_{eff}\rangle$, and $\langle \log g\rangle$ values lead to $\langle M_v\rangle = 0^m9$ and $\mathfrak{M} = 0.6\ \mathfrak{M}_\odot$. Some peculiarities in the behavior of the m_1 index are discussed. The mean m_1 value at light minimum indicates that SW And has a near solar abundance of heavy elements.

Key words: RR Lyrae variable—photometry—physical elements—Wesselink's method

Introduction

SW Andromedae ($\alpha = 00^h18^m29^s$, $\delta = 28°50'.8$ (1900), 9.34–10.76 *B*, A7 III–F8 III) is an RR Lyrae (RRab) variable with a period of 0^d442. The period is apparently decreasing in proportion to time (Tsesevich 1969). Preston (1959) concludes that SW And is a member of the strong-line group ($\Delta s = 0$) of RR Lyrae variable stars. A reproduction of an excellent single-trail spectrogram of SW And in the region of the K line is given by Preston and Paczynski (1964). The strong-line nature of the star is clearly evident in their reproduction.

We have undertaken a photometric study of this strong-line variable to (1) assess the reliability of applying Wesselink's method to determining the radius of the star, and (2) investigate the behavior of the m_1 index with phase. Our interest in these two issues stems from our investigation of dwarf cepheids. For these stars there are no independent checks on the radii and the m_1 index appears to behave in an anomolous way during the pulsation cycle in the sense that it frequently does not show changes as anticipated from the temperature variations. Since the radii of the RR Lyrae stars are known to an accuracy of $\sim$ 10%, the radii determined from Wesselink's method can be checked. Satisfactory agreement would imply that the radii derived for the dwarf cepheids by Wesselink's method are also reliable since they have light and velocity curves similar in shape to those exhibited by RR Lyrae stars. Since the RR Lyrae stars exhibit a larger light amplitude and color variation than the dwarf cepheids the behavior of the m_1 index should also be instructive.

We have selected SW And to study because it has essentially a solar abundance of heavy elements.

Observations

One hundred and twenty $uvby\beta$ photometric observations of SW And were secured with a sky-compensating photoelectric photometer attached to the 61-cm (24-inch) reflecting telescope at Brigham Young University. The photometer is equipped with a standard $uvby\beta$ filter set and a 1P21 photomultiplier as the light-sensitive unit.

The *uvby* observations were obtained differentially with respect to the comparison star HD 1826 ($\alpha = 0^h17^m.6$, $\delta = 28°55'$ (1900), $6^m.9$, A3). The tie-in to the standard *uvby* system was made by 30 observations of standard stars on the three nights used to secure the observations. The following average values and errors (internal probable errors of the means) were measured and adopted for the comparison star: $y = 6^m898 \pm 0.001$, $(b-y) = 0^m094 \pm 0.001$, $m_1 = 0^m231 \pm 0.002$, $c_1 = 1^m000 \pm 0.004$, and $\beta = 2^m860 \pm 0.001$. Values of β' for SW And were reduced directly to the standard β system without utilizing the comparison stars as an intermediary. The large m_1 value of HD 1826 suggests that it is a metallic-line star.

The observations of SW And are tabulated in Table I according to the heliocentric Julian day and phase calculated from the light elements

$$\mathrm{JD}_\odot\ (\mathrm{max}) = 2443067.6819 \pm 0.44227 \quad . \qquad (1)$$

These elements fit the two light maximum covered by our data. The remarks about SW And in the *General Catalogue of Variable Stars* indicates the form of the light curve changes in a period of $36^d.83$ and the period is slowly decreasing. Therefore, the epoch and the period given above are appropriate for only the short time interval covered by our observations.

The probable errors in the photometry of SW And (single observation) at light minimum are $\pm 0^m005(y)$, $\pm 0^m007(b-y)$, $\pm 0^m012(m_1)$, $\pm 0^m011(c_1)$, and $\pm 0^m011$ in β. The observations given in Table I are displayed in Figure 1 as a function of phase.

Analysis and Discussion

An examination of the $y = V$ light curve of SW And indicates a light range of 0^m925 (9^m100–10^m025).

TABLE I

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JD (Hel.) 2443000.+	Phase	$y = V$	$(b-y)$	m_1	c_1	β
67.6454	0.9157	9.676	0.293	0.116	0.730	2.676
.6474	0.9202	9.628	0.267	0.144	0.732	2.705
.6493	0.9244	9.592	0.240	0.133	0.785	2.727
.6572	0.9423	9.414	0.211	0.187	0.882	2.770
.6590	0.9465	9.414	0.211	0.152	0.930	2.771
.6610	0.9509	9.388	0.195	0.162	0.944	2.776
.6683	0.9675	9.277	0.154	0.165	1.088	-
.6706	0.9725	9.197	0.181	0.116	1.150	2.820
.6727	0.9774	9.152	0.162	0.164	1.118	2.793
.6810	0.9961	9.100	0.135	0.148	1.214	2.791
.6831	0.0009	9.104	0.122	0.166	1.214	2.796
.6851	0.0055	9.104	0.126	0.162	1.231	2.803
.6930	0.0232	9.120	0.140	0.168	1.214	2.784
.6951	0.0281	9.118	0.164	0.144	1.222	2.766
.6972	0.0328	9.141	0.158	0.137	1.248	2.787
.7052	0.0508	9.180	0.165	0.143	1.226	2.736
.7071	0.0552	9.186	0.167	0.145	1.235	2.744
.7091	0.0597	9.207	0.149	0.176	1.203	2.771
.7342	0.1164	9.325	0.200	0.134	1.188	2.741
.7362	0.1210	9.325	0.203	0.152	1.147	2.718
67.7382	0.1255	9.339	0.204	0.138	1.178	2.703
69.6093	0.3563	9.705	0.324	0.154	0.811	2.644
.6114	0.3609	9.691	0.334	0.172	0.779	2.598
.6135	0.3657	9.693	0.345	0.135	0.820	2.630
.6223	0.3856	9.721	0.351	0.081	0.913	2.651
.6243	0.3901	9.709	0.369	0.079	0.895	2.636
.6263	0.3946	9.713	0.375	0.076	0.852	2.637
.6524	0.4537	9.780	0.366	0.121	0.777	2.600
.6551	0.4597	9.799	0.351	0.152	0.755	2.622
.6570	0.4641	9.809	0.344	0.151	0.790	2.666
.6592	0.4689	9.814	0.373	0.112	0.791	2.666
.6611	0.4733	9.807	0.379	0.125	0.701	2.670
.6735	0.5013	9.806	0.404	0.065	0.789	2.658
.6756	0.5062	9.807	0.367	0.131	0.778	2.624
.6776	0.5107	9.808	0.375	0.121	0.837	2.607
.6900	0.5386	9.857	0.368	0.113	0.782	2.637
.6921	0.5434	9.860	0.330	0.167	0.730	2.654
.6941	0.5479	9.858	0.344	0.142	0.763	2.658
.7052	0.5731	9.872	0.360	0.132	0.777	2.613
.7072	0.5775	9.858	0.369	0.136	0.770	2.598
.7091	0.5818	9.862	0.348	0.177	0.714	2.599
.7183	0.6027	9.860	0.374	0.102	0.814	2.646
.7205	0.6075	9.851	0.380	0.109	0.759	2.662
.7226	0.6123	9.854	0.377	0.123	0.716	2.626
.7248	0.6173	9.862	0.353	0.183	0.673	2.606
.7271	0.6225	9.866	0.355	0.168	0.722	2.602
.7382	0.6477	9.871	0.366	0.117	0.782	2.642
.7401	0.6520	9.881	0.360	0.125	0.781	2.658
.7422	0.6568	9.909	0.322	0.178	0.764	2.641
.7611	0.6994	9.947	0.342	0.148	0.770	2.636
.7631	0.7039	9.932	0.353	0.136	0.850	2.628
.7650	0.7083	9.932	0.349	0.160	0.819	2.615
.7671	0.7131	9.936	0.354	0.145	0.788	2.628
.7693	0.7179	9.926	0.364	0.149	0.758	2.611
.7773	0.7360	9.958	0.363	0.155	0.752	2.614
.7794	0.7407	9.991	0.342	0.183	0.740	2.574
.7815	0.7454	9.994	0.351	0.187	0.687	2.634
.7893	0.7633	10.016	0.369	0.132	0.738	2.643
.7914	0.7679	10.007	0.380	0.144	0.690	2.648
.7934	0.7724	9.993	0.390	0.141	0.708	2.657
.7954	0.7770	10.008	0.365	0.168	0.732	2.657
.7974	0.7814	10.024	0.360	0.166	0.760	2.624
.8060	0.8011	9.988	0.415	0.087	0.767	2.620
69.8081	0.8057	10.012	0.404	0.109	0.744	2.614
69.8102	0.8104	10.046	0.363	0.159	0.725	2.600
.8127	0.8161	10.050	0.347	0.176	0.713	2.600
.8147	0.8207	10.028	0.382	0.151	0.637	2.619
.8233	0.8400	10.037	0.351	0.167	0.736	2.587
.8254	0.8447	10.015	0.372	0.139	0.748	2.623
.8274	0.8493	10.014	0.378	0.125	0.741	2.624
.8354	0.8674	9.998	0.369	0.129	0.725	2.677
.8373	0.8718	9.966	0.368	0.113	0.758	2.653
69.8394	0.8764	9.965	0.370	0.111	0.725	2.667
71.6041	0.8666	10.038	0.353	0.140	0.787	2.674
.6060	0.8709	10.033	0.349	0.141	0.783	2.683
.6078	0.8749	10.013	0.365	0.103	0.799	2.669
.6160	0.8934	9.913	0.333	0.103	0.828	2.648
.6180	0.8981	9.919	0.288	0.180	0.759	2.669
.6201	0.9028	9.867	0.284	0.174	0.768	2.681
.6284	0.9216	9.616	0.268	0.156	0.758	2.672
.6304	0.9260	9.544	0.268	0.127	0.786	2.663
.6323	0.9304	9.512	0.247	0.130	0.818	2.726
.6409	0.9498	9.395	0.219	0.140	0.959	2.767
.6428	0.9541	9.372	0.194	0.151	1.022	2.756
.6448	0.9585	9.334	0.188	0.160	1.066	2.775
.6547	0.9811	9.166	0.147	0.153	1.192	2.789
.6566	0.9854	9.127	0.150	0.148	1.181	2.816
.6586	0.9898	9.123	0.132	0.173	1.194	2.780
.6661	0.0067	9.119	0.121	0.171	1.244	2.756
.6680	0.0111	9.128	0.123	0.156	1.233	2.757
.6700	0.0156	9.144	0.114	0.177	1.232	2.792
.6788	0.0355	9.178	0.148	0.156	1.251	2.777
.6807	0.0399	9.185	0.162	0.139	1.240	2.756
.6828	0.0445	9.181	0.184	0.113	1.246	2.759
.6900	0.0608	9.214	0.173	0.146	1.236	2.759
.6917	0.0647	9.232	0.176	0.136	1.244	2.759
.6937	0.0691	9.262	0.154	0.172	1.222	2.749
.7013	0.0864	9.285	0.196	0.125	1.199	2.728
.7029	0.0901	9.301	0.189	0.154	1.170	2.725
.7046	0.0939	9.302	0.184	0.158	1.193	2.726
.7137	0.1143	9.353	0.200	0.140	1.179	2.724
.7156	0.1188	9.357	0.208	0.145	1.156	2.715
.7178	0.1237	9.358	0.218	0.130	1.152	2.713
.7251	0.1402	9.392	0.225	0.156	1.102	2.698
.7270	0.1445	9.403	0.225	0.144	1.105	2.710
.7289	0.1489	9.407	0.220	0.169	1.082	2.699
.7365	0.1660	9.433	0.244	0.162	1.019	2.730
.7385	0.1705	9.463	0.232	0.160	1.042	2.703
.7405	0.1750	9.478	0.227	0.161	1.055	2.696
.7484	0.1930	9.474	0.277	0.120	1.029	2.687
.7507	0.1981	9.480	0.281	0.123	1.019	2.702
.7526	0.2024	9.512	0.250	0.166	0.971	2.713
.7666	0.2339	9.548	0.278	0.168	0.930	2.680
.7688	0.2389	9.545	0.296	0.141	0.906	2.669
.7710	0.2439	9.562	0.291	0.143	0.899	2.663
.7793	0.2627	9.569	0.328	0.111	0.892	2.649
.7813	0.2672	9.590	0.324	0.113	0.914	2.641
.7833	0.2718	9.611	0.316	0.121	0.932	2.663
.7925	0.2926	9.631	0.310	0.144	0.884	2.675
.7947	0.2976	9.646	0.325	0.105	0.915	2.693
.7966	0.3020	9.658	0.318	0.108	0.919	2.693
.8046	0.3200	9.678	0.297	0.186	0.839	2.660
.8068	0.3248	9.669	0.319	0.153	0.843	2.660
.8089	0.3296	9.663	0.342	0.137	0.841	2.681
.8169	0.3479	9.675	0.349	0.133	0.825	2.640
.8193	0.3531	9.675	0.358	0.098	0.876	2.656
71.8212	0.3576	9.693	0.339	0.136	0.829	2.643

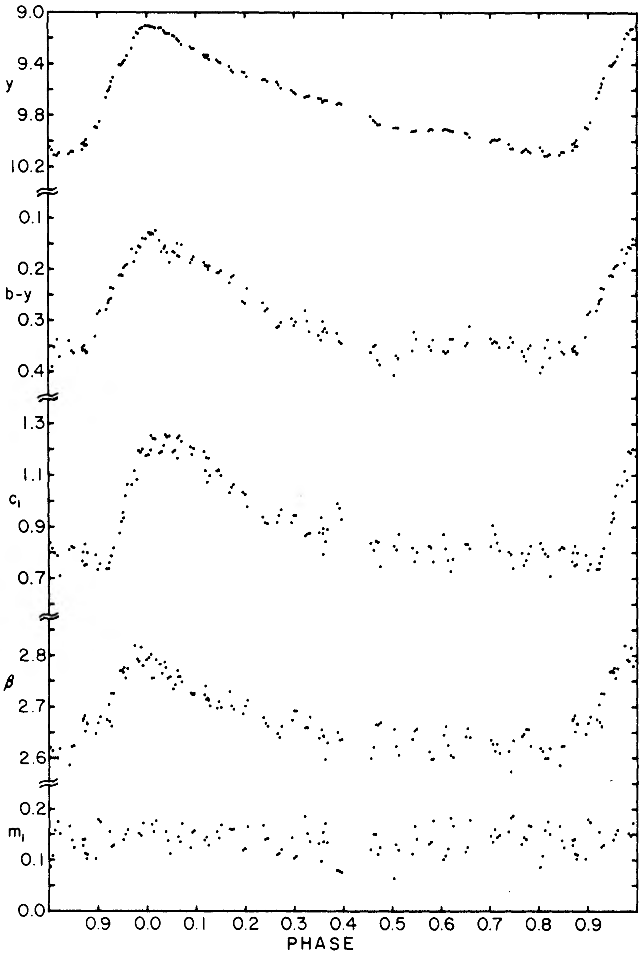

FIG. 1—Light and color-index variations of SW And in the *uvbyβ* photometric system.

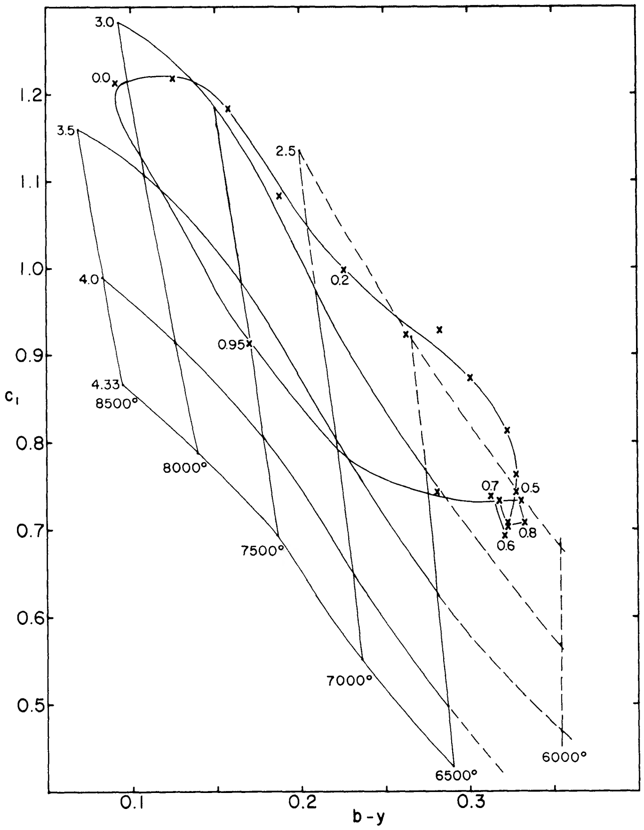

FIG. 2—The loop traversed by SW And in the $c_1,(b-y)$ diagram. Phases are indicated by numbers around the loop. The log g and effective temperature lines are based on Breger's (1977) calibration. The dashed lines are extrapolations of the calibration.

The small galactic latitude ($b = -15\overset{\circ}{.}7$) and relative faintness of the star suggest that the star may be reddened. We have utilized the Crawford (1973, 1975) calibrations to calculate the reddening of both the standard star and the variable. The color excess of HD 1826 is $E(b-y) = 0\overset{m}{.}020$ and the average color excess (around the light cycle) of SW And is $E(b-y) = 0\overset{m}{.}036$. Although the Crawford calibrations are based on stars of higher surface gravity than SW And they appear to give reasonable intrinsic color indices ($\sim \pm 0\overset{m}{.}01$) for SW And. We adopt $E(b-y) = 0\overset{m}{.}036$ for SW And since it is more distant than the comparison star. By adopting this color excess we find $(b-y)_0 = 0\overset{m}{.}09$ at light maximum and $(b-y)_0 = 0\overset{m}{.}33$ at light minimum.

In order to calculate the temperatures and effective surface gravities as a function of phase, normals of $(b-y)$ and c_1, corrected for reddening, at every 0.05 in phase have been formed. The normal points are plotted in the $c_1,(b-y)$ diagrams shown in Figure 2. Constant temperature and gravity lines (solid lines) are based on the Breger (1977) calibration, the dashed lines are extrapolations made with the aid of the Kurucz (1975) models. SW And traverses a loop in the $c_1,(b-y)$ diagram; phases are indicated at a number of positions around the loop. At maximum light the effective temperature of SW And is 8100 K and at minimum light the effective temperature is 6200 K. A mean effective temperature of $\langle T_{\rm eff} \rangle = 6680$ K is found over the pulsation cycle. The estimated standard errors in the temperature values are ~ 150 K.

The average effective surface gravity over the pulsation cycle is $\langle \log g \rangle = 2.80$. A somewhat higher value ($\log g \simeq 3.0$) is suggested by the observational data near maximum light where the calibration is more secure. We have adopted $\langle \log g \rangle = 2.9 \pm 0.1$ as the best value, thus placing greater weight on the data secured near light maximum than light minimum. Because of the uncertainty in the reddening and in the extrapolations to lower surface gravities and temperature we estimate the uncertainty (s.d.) in $\langle \log g_{\rm eff} \rangle$ to be $\simeq 0.1$. A check on the change in the effective surface gravity inferred from the loop during the pulsation cycle can be made by calculating the acceleration of the atmosphere of SW And from the velocity curves of Preston and Paczynski (1964) and Bonsack (1957). The maximum acceleration on the descending branch ($0^P_.92$) of the velocity curve is 3.6×10^3 cm sec^{-2} and on the ascending branch ($0^P_.4$) is -3.1×10^2 cm sec^{-2}. A factor 1.34 has been used to convert the measured radial velocities to radius variations. If the accelerations are added and subtracted to the average gravity we find $\log g_{\rm eff} = 3.6$ and $\log g_{\rm eff} = 2.4$ in good agreement with the maximum and minimum values inferred from the loop in Figure 2. It is evident that all, or essentially all, the variations in c_1 and $(b-y)$ are caused by changes in temperature and effective surface gravity. SW And does exhibit weak emission in the hydrogen lines (Preston and Paczynski 1964) for a short time interval (12 min in Hγ) near phase $0^P_.92$. This emission could make a small contribution at the Balmer continuum at this phase.

As pointed out in the introduction, the primary aim of this study is to apply Wesselink's method to determine the radius of SW And. This method of finding the radius of a pulsating star involves comparing the radius change, revealed from the velocity curve, with changes in the color and light curves. This is done by selecting pairs of points at which the colors are equal and finding the corresponding differences in magnitude and comparing these values with the changes in radius found from integrating the velocity curve. If the temperatures are equal at two phases then the difference in magnitude is due entirely to the change in the radius. Both Wooley and Savage (1971) and Breger (1975) have emphasized that phase pairs of equal color do not necessarily yield phase pairs of equal temperature because the radiation emitted is a function of both temperature and effective surface gravity. Color indices must be corrected for the effects of surface gravity to yield phase pairs of equal temperature.

Smoothed y, $(b-y)$, and $(v-y)$ curves of SW And were used to estimate magnitude differences and find phase pairs of equal temperature. The $(b-y)$ and $(v-y)$ color-index curves were corrected for the gravity corrections $-0.021\ \delta(\log g)$ and $-0.038\ \delta(\log g)$, respectively. The well-determined velocity curve (metal lines) of the descending branch of SW And (Preston and Paczynski 1964) was combined with the ascending-branch velocity measurements of Bonsack (1957) to yield a complete velocity curve that was integrated for radial displacement.

Sixteen phase pairs were selected (mean values adopted from the $(b-y)$ and $(v-y)$ curves). In Figure 3 the difference in magnitude for the 16 points are plotted against the difference in radial displacement. The x's are phase pairs selected on the ascending and descending branches of the light curve while the +'s indicate phase pairs between 0.5–0.84 where the temperature and surface gravity are essentially constant but the light curve still exhibits a decrease in light. Note that phase pairs selected on the ascending and descending branches of the light curve yield somewhat smaller Δm values or larger $(R_1 - R_2)$ values than the phase pairs selected in the phase interval $0.5-0.84$. The RR Lyrae variables are known to have a velocity gradient in their atmospheres. As pointed out by Oke, Giver, and Searle (1962), $(R_1 - R_2)$ can only be derived with accuracy from the velocity curve if the velocity data refer to the same mass layer. This condition is not fulfilled when the pressures are different at two identical temperatures. Thus the $(R_1 - R_2)$ values derived at phase pairs near light maximum should be suspect since the gas pressures are quite different at the two phase pairs. On the other hand, the $T_{\rm eff}$ and $\log g_{\rm eff}$ values are practically constant over the phase interval 0.50–0.84 and therefore the velocity data refer to the same infalling mass layer. This suggests that greater

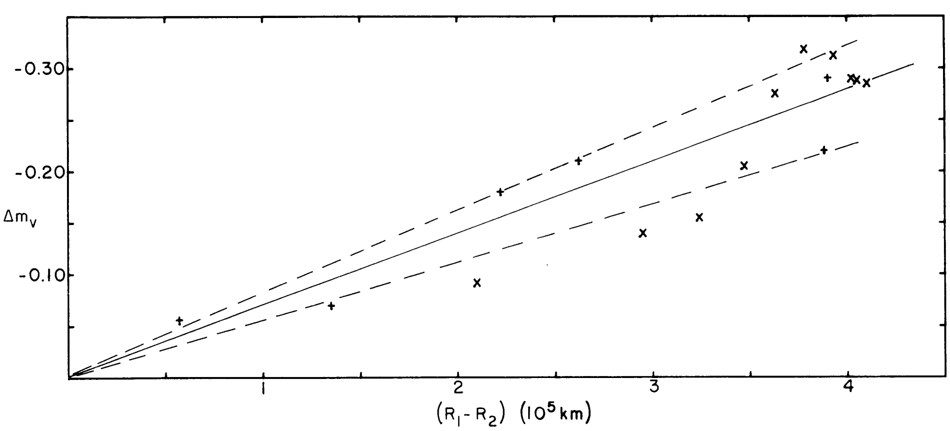

FIG. 3—Application of Wesselink's method of determining the radius for SW And. Phases of equal temperature have been chosen to obtain ΔM_v and $(R_1 - R_2)$ values. The x's are phase pairs selected on the ascending and descending branches of the light curve and the +'s indicate phase pairs between $0^P_.5$–$0^P_.84$. The solid line yields a radius of 4.45 $R_\odot$. The dashed lines are discussed in the text.

weight should be assigned to phase pairs in the phase interval 0.5–0.84.

The solid line is the best eye fit through the data points. Greater weight has been given to the phase pairs in the interval 0.5–0.84. The mean radius is given by the equation

$$\langle R\rangle = -2.17(R_1-R_2)/\Delta m_v \quad . \qquad (2)$$

We find $\langle R\rangle = 4.45\ R_\odot$. If we adopt $\langle T_{eff}\rangle = 6680$ K and $M_{bol\odot} = +4^m.75$, the absolute magnitude of SW And is $\langle M_v\rangle = 0^m.9$. Some insight into the errors of the mean values can be gained by calculating the radii and the M_v values from the two dashed lines in Figure 3. The upper line yields $\langle R\rangle = 3.96\ R_\odot$, and $\langle M_v\rangle = 1^m.2$; the lower line yields $\langle R\rangle = 5.4\ R_\odot$, and $\langle M_v\rangle = 0^m.5$. It is apparent from these values that the standard errors (internal) of the mean values are $\sim \pm 0.2$ in R and $\pm 0^m.2$ in M_v. The mean absolute magnitude, $\langle M_v\rangle = 0^m.9$, and $\langle R\rangle = 4.5\ R_\odot$ can be compared with $M_v = 0^m.8$ and $R = 4.5\ R_\odot$ found by Wooley and Savage (1971) for a group of short-period, strong-metal-line variables similar to SW And. We conclude that when accurate light and color curves are available, and corrections for the effects of surface gravity on color indices are taken into account, the Wesselink method is capable of yielding accurate radii. We can also be confident that the method should yield accurate radii for at least those dwarf cepheids in which stable light and velocity curves are observed.

Since $g \simeq \mathfrak{M}/R^2$, the mass of SW And can be calculated from the $\langle \log g_{eff}\rangle$ value and radius. If $\mathfrak{M}$ and R are expressed in terms of the sun's values, the mass is given by

$$\log \mathfrak{M} = \log g + 2 \log R - 4.44 \quad . \qquad (3)$$

Equation (3) yields $\mathfrak{M} = 0.6\mathfrak{M}_\odot \pm 0.2$ for SW And.

The m_1 index decreases by $\sim 0^m.03$ from phase 0.0 to phase 0.5 (see Fig. 1) as predicted by the standard Crawford calibrations for lower luminosity stars. In the phase interval 0.5 to 0.75, however, the m_1 index appears to increase when it should be constant. At 0.75, near minimum light, the m_1 index is essentially identical to its value at light maximum. Little change in m_1 is apparent in the rise from minimum to maximum light. The same behavior of the m_1 index is observed in the dwarf cepheid RS Gruis, (McNamara and Feltz 1976), i.e., an apparent increase in m_1 from phase 0.5 to 0.8 and little or no change in the rise from minimum to maximum light.

In view of the peculiar behavior of the m_1 index of SW And with phase and the star's low surface gravity, relating the m_1 index to [Fe/H] through the Crawford-Perry (1976) calibration cannot be depended on to yield accurate results. If, however, we adopt the mean m_1 value ($0^m.143$) in the interval 0.5–0.8 and correct it for reddening we find $\langle (m_1)_0\rangle = 0^m.154$. The Crawford-Perry calibration yields [Fe/H] $= -0.19$. Since the uncertainty in this value is at least ± 0.2 we have only succeeded in showing that the heavy element abundance in SW And is near the solar value which is already clear from the spectrograpic results.

A summary of the basic physical parameters of SW And derived in this study is given in Table II.

TABLE II

Parameters of SW And

Parameter	Value	σ
ΔV	$0^m.925$*	$\pm 0^m.005$
E(b-y)	$0^m.036$	$\pm 0^m.010$
$(b-y)_0$ max	$0^m.09$*	$\pm 0^m.015$
$(b-y)_0$ min	$0^m.33$*	$\pm 0^m.015$
$\langle (m_1)_0\rangle$ $0^p.5-0^p.8$	$0^m.154$	$\pm 0^m.005$
$\langle T_{eff}\rangle$	6680 K	±150 K
$\langle \log g_{eff}\rangle$	2.9	±0.1
$R/R_\odot$	4.45	±0.2
$\langle M_v\rangle$	0.9	±0.2
Mass (☉)	0.6	±0.15

*May vary over a 36-day cycle.

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