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THE BAADE-WESSELINK METHOD AND THE DISTANCES TO RR LYRAE STARS. I. THE FIELD STAR VY SERPENTIS

BRUCE W. CARNEY[1]
University of North Carolina, Chapel Hill
AND
DAVID W. LATHAM
Harvard-Smithsonian Center for Astrophysics
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ABSTRACT

We discuss the desirability and feasibility of determining distances to globular clusters independently of field star calibrations using the Baade-Wesselink method. As a preliminary test of the method, we present simultaneous accurate photometric and radial velocity data for the cool, lightly reddened field RR Lyrae variable VY Serpentis. We use the data to solve for the star's radius and distance, using two versions of the Baade-Wesselink method that each allow for the star's low metallicity and its changing gravity. For both versions of the method we find a phase difference, $\Delta\phi \sim 0.075$, between the photometric and spectroscopic radii. We conclude that the problem arises not from the method or its basic assumptions, but rather from our choice of a star with strong convection which has not been properly taken into account.

Subject headings: stars: individual — stars: pulsation — stars: RR Lyrae

I. INTRODUCTION

RR Lyrae variables are valuable distance indicators because they are numerous, readily identifiable, and relatively bright ($L \sim 50\ L_\odot$). Further, for each globular cluster in which they are found, they lie on the horizontal branch, so that each variable has the same mean apparent visual magnitude as any other. The simplest, though not necessarily correct, interpretation is that all RR Lyraes have the same absolute magnitude, which of course significantly enhances their value as distance indicators.

An adopted value for $\langle M_v \rangle_{\rm RR}$, the mean absolute visual magnitude of the RR Lyraes, may be used to obtain the distance to the galactic center by studies of their numbers versus apparent magnitude in the direction of Baade's window or by establishing the distance to the globular clusters' distribution centroid (see Harris 1976 and references therein). RR Lyraes have been identified in the Magellanic Clouds and, with the advent of the Space Telescope, will likely be seen in other galaxies in and even beyond the Local Group. Integrated globular cluster absolute magnitudes inferred from $\langle M_v \rangle_{\rm RR}$ may also be used to derive distances to galaxies (Hanes 1979, 1982). The distances to globular clusters are also critical for estimations of their ages via the luminosity of stars at the main sequence turnoff, and may provide evidence on the clusters' helium content as well.

Four methods have been used to estimate $\langle M_v \rangle_{\rm RR}$: (1) statistical parallax analyses of field stars (van Herk 1965; Woolley and Savage 1971; Heck 1973; Clube and Jones 1971, 1974; Hemenway 1975); (2) fitting field halo dwarfs with accurate trigonometric parallaxes to globular cluster main sequences (Sandage 1970; Carney 1980); (3) observations of RR Lyraes in the Magellanic Clouds, whose distances may be estimated by other means (Graham 1973, 1975); and (4) Baade-Wesselink analyses of field variables (McDonald 1977; Siegel 1980; Manduca *et al.* 1981). Each method has its own virtues and shortcomings, but in general they agree that $\langle M_v \rangle_{\rm RR} \sim +0.6 \pm 0.2$ mag.

Is it really true that all RR Lyraes have the same mean absolute visual magnitude? Theoretical models (cf. Iben and Rood 1970; Sweigart and Gross 1976) indicate that $\langle M_v \rangle_{\rm RR}$ depends primarily on the helium mass fraction, Y, and the stellar core mass, which in turn depends on age, prior mass loss, rotation, mixing, and composition. The observational evidence is inconclusive, in our opinion. Variations of $\langle M_v \rangle_{\rm RR}$ with metallicity have been claimed from some of the statistical parallax analyses and main sequence fitting, but the variables in ω Cen show no such trend in spite of their wide range in metallicity (Butler, Dickens, and Epps 1978). The period-luminosity-amplitude relation discussed by Sandage (1981*a*, *b*, *c*) and Sandage, Katem, and Sandage (1981) indicates variations in $\langle M_v \rangle_{\rm RR}$ from cluster to cluster, although the interpretation that this is a helium abundance effect is open to question, based on main sequence data (Carney 1981) and the width of the instability strip (Deupree 1977).

Direct distance determinations to globular clusters would avoid the use of field stars as distance calibrators. In view of recent suggestions (Kraft *et al.* 1982; Kraft 1982) that the field and cluster stars may have experienced different chemical histories, we feel this is important. Direct measures would also provide a test of the period-luminosity-amplitude relation recently proposed by Sandage and his collaborators (Sandage, Katem, and Sandage 1981; Sandage 1981*b*, *c*). The absolute distances are of course critical in deriving cluster age estimates.

Of the four above methods for estimating $\langle M_v \rangle_{\rm RR}$, only the Baade-Wesselink method offers us a chance to directly measure distances to individual globular clusters. With the advent of modern radial-velocity spectrometers on large

[1] Visiting Astronomer, Cerro Tololo Inter-American Observatory, which is operated by AURA, Inc., under contract with the National Science Foundation.

telescopes, such as the digital speedometer on the MMT (Latham *et al.* 1983), it is now possible to obtain the accurate radial velocity curves required for this technique. Before investing large amounts on telescope time on cluster variables, however, we have set out to test the method on a few selected bright field stars.

For our first target, we chose VY Serpentis (HD 138279; BD $+2°2972$; $\alpha = 15^h28^m30^s$, $\delta = +01°51'12''$, 1950.0), which is as metal-poor as the globular clusters we propose to study, is only slightly reddened, and does not show any sign of the Blazhko effect (a periodic modulation of the pulsational amplitude). The basic properties have been discussed by Carney and Jones (1983), who found $[\mathrm{Fe/H}] = -1.77$, $E(B-V) = 0.03 \pm 0.01$ mag, based on reddenings derived for nearby stars obtained by other workers, and that the star has extreme kinematical properties, including a velocity in the galactic rest frame of 460 ± 70 km s^{-1}.

II. OBSERVATIONS

a) *Radial Velocities*

The radial velocities were obtained by D. W. L. during 1981 May 11–19 with the 1.5 m Tillinghast reflector at the Smithsonian's Whipple Observatory atop Mount Hopkins, Arizona. An echelle spectrograph and photon-counting Reticon (Latham 1982) were used to record 50 Å of a digital spectrum centered at 5200 Å with a dispersion of 2.1 Å mm^{-1} and a resolution of 10 km s^{-1}. Each 10-minute exposure of VY Ser was subsequently correlated against a high signal-to-noise spectrum of 68 Tau using procedures similar to those outlined by Tonry and Davis (1979, 1981). In Figure 1 we show a typical mean-light exposure of the spectrum of VY Ser along with the corresponding correlation plot. Table 1 lists our final heliocentric velocities, the internal error estimates, and the phase of VY Ser at midexposure. Our experience with repeated measures of nonvariable stars suggests that the internal error estimates are too optimistic by about a factor of 2. Still, the precision of our velocities should be better than 1 km s^{-1} most of the time. The absolute zero point of our system has been determined from a large set of observations of IAU standards and the twilight sky (Latham *et al.* 1983), and we believe our zero point is accurate to better than 0.5 km s^{-1}.

The ephemeris given by Kukarkin *et al.* (1970) predicts:

$$\text{Max. light} = \text{JD } 2{,}431{,}225.341 + 0.71409384E \, . \qquad (1)$$

Cycle 18,924 maximum light should occur at JD 2,444,738.853. Averaging over the photometric and radial velocity peaks, we adopted $\phi = 0.00$ at JD 2,444,738.869. Conversion to the ephemeris of equation (1) is thus accomplished by adding 0.016 to our computed phases. The radial velocities are plotted in Figure 2, with different symbols for different nights.

b) *Photometry*

B. W. C. obtained *uvbyV* photometry of VY Ser during 1981 May 12–15 at Cerro Tololo Inter-American Observatory

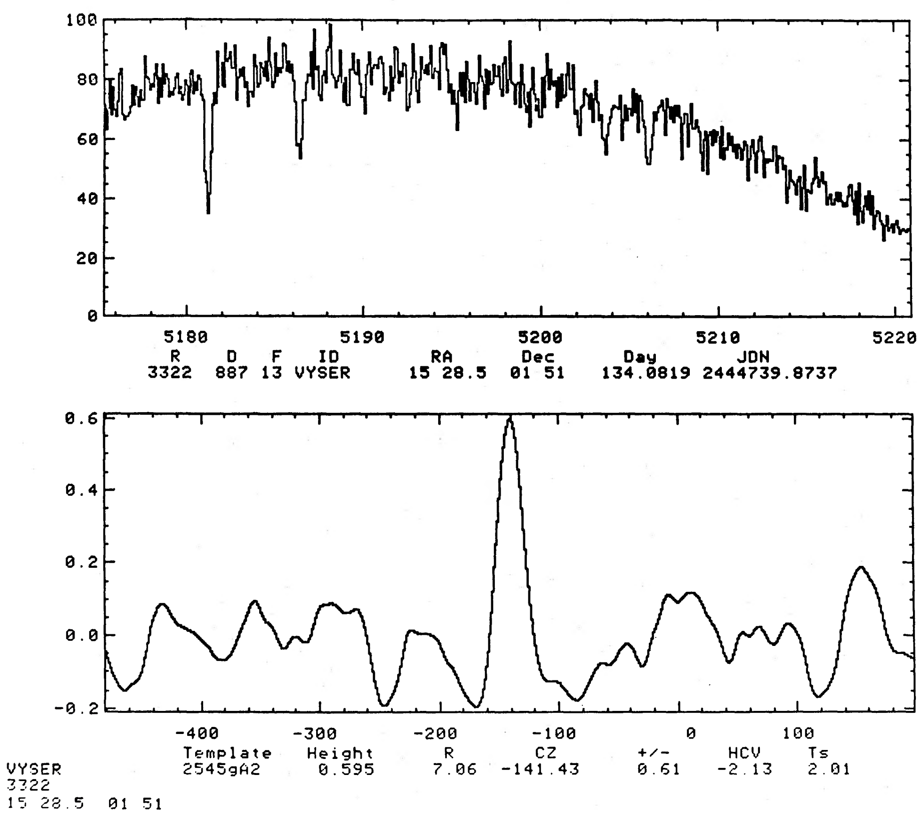

FIG. 1.—*Upper*, a typical digital spectrum of VY Ser near mean light ($\phi = 0.407$), taken at JD 2,444,739.8737. *Bottom*, the correlation spectrum of the above spectrum with a high signal-to-noise template of 68 Tau. The heliocentric velocity is -141.43 ± 0.61 (internal) km s^{-1}, and the correlation coefficient R (Tonry and Davis 1979, 1981) is 7.06.

TABLE 1

RADIAL VELOCITIES

J.D. (-2444700)	v_{rad}(km sec^{-1})	σ (km sec^{-1})	φ
36.7312	-170.6	0.7	0.0063
36.7397	-170.6	0.6	0.0182
36.7480	-171.2	0.5	0.0298
36.7585	-169.9	0.6	0.0445
36.7668	-169.8	0.5	0.0561
36.7751	-168.5	0.6	0.0678
36.7835	-167.0	0.5	0.0795
36.7914	-165.7	0.6	0.0906
36.7995	-164.6	0.5	0.1019
36.8070	-162.8	0.4	0.1124
36.8154	-162.9	0.4	0.1242
36.8258	-160.9	0.5	0.1388
36.8335	-160.8	0.5	0.1495
36.8418	-159.1	0.5	0.1612
36.8502	-158.5	0.5	0.1729
36.8584	-158.1	0.4	0.1844
36.8661	-157.7	0.3	0.1952
36.8743	-156.4	0.5	0.2067
36.8827	-154.3	0.5	0.2184
36.8910	-154.6	0.4	0.2301
36.9021	-153.4	0.5	0.2456
36.9118	-152.2	0.4	0.2592
36.9202	-152.0	0.5	0.2710
36.9285	-150.1	0.4	0.2826
36.9375	-148.4	0.6	0.2952
36.9459	-148.1	0.5	0.3069
36.9542	-147.1	0.4	0.3186
36.9646	-145.2	0.5	0.3331
36.9729	-144.8	0.5	0.3447
37.7160	-142.0	0.4	0.3854
37.7250	-141.0	0.4	0.3980
37.7327	-139.4	0.4	0.4088
37.7410	-140.0	0.4	0.4204
37.7493	-138.5	0.4	0.4320
37.7577	-138.7	0.4	0.4438
37.7653	-138.5	0.4	0.4544
37.7792	-136.4	0.5	0.4739
37.7875	-136.1	0.4	0.4855
37.7959	-136.0	0.4	0.4973
37.8042	-135.7	0.5	0.5089
37.8118	-134.7	0.4	0.5195
37.8202	-134.2	0.4	0.5313
37.8285	-134.6	0.5	0.5429
37.8368	-133.6	0.5	0.5545
37.8459	-133.5	0.5	0.5673
37.8542	-132.5	0.4	0.5789
37.8625	-132.2	0.5	0.5905
37.8709	-131.6	0.6	0.6023
37.8792	-132.2	0.5	0.6139
37.8875	-131.0	0.5	0.6255
37.8972	-130.5	0.6	0.6391
37.9056	-129.5	0.4	0.6509
37.9139	-130.8	0.5	0.6625
37.9223	-129.6	0.5	0.6743
38.7247	-122.8	0.4	0.7979
38.7327	-124.6	0.5	0.8091
38.7403	-125.0	0.5	0.8198
38.7486	-126.9	0.6	0.8314
38.7563	-128.9	0.5	0.8422
38.7639	-132.2	0.6	0.8528
38.7716	-138.4	0.6	0.8636
38.7792	-147.0	0.6	0.8742
38.7875	-155.7	0.6	0.8859
38.7952	-158.9	0.7	0.8967
38.8028	-162.6	0.6	0.9073
38.8111	-165.6	0.5	0.9189
38.8188	-167.1	0.5	0.9297
38.8278	-167.8	0.6	0.9423
38.8375	-170.1	0.5	0.9559
38.8452	-170.2	0.5	0.9667
38.8528	-170.2	0.5	0.9773
38.8604	-171.0	0.5	0.9880
38.8688	-170.8	0.5	0.9997
38.8764	-171.1	0.5	0.0104

TABLE 1—*Continued*

J.D. (−2444700)	v_{rad}(km sec^{-1})	σ (km sec^{-1})	φ
38.8847	−171.1	0.4	0.0220
38.8924	−169.5	0.5	0.0328
38.9007	−168.3	0.5	0.0444
38.9084	−168.5	0.4	0.0552
38.9160	−167.3	0.4	0.0658
38.9243	−165.4	0.4	0.0774
39.7528	−153.5	0.3	0.2377
39.7611	−153.5	0.4	0.2493
39.7688	−151.9	0.4	0.2601
39.7778	−150.6	0.4	0.2727
39.7854	−150.6	0.4	0.2833
39.7931	−149.6	0.5	0.2941
39.8007	−149.1	0.7	0.3047
39.8313	−140.2	0.6	0.3476
39.8389	−143.6	0.4	0.3582
39.8472	−144.2	0.4	0.3698
39.8563	−143.0	0.4	0.3826
39.8653	−141.3	0.5	0.3952
39.8736	−141.4	0.4	0.4068
39.8813	−139.7	0.5	0.4176
39.8896	−138.5	0.5	0.4292
39.8979	−137.5	0.4	0.4408
39.9077	−136.7	0.5	0.4546
39.9160	−137.2	0.4	0.4662
39.9236	−136.3	0.4	0.4768
40.7042	−134.4	0.6	0.5700
40.7118	−135.1	0.7	0.5806
40.7278	−132.7	0.7	0.6030
40.7361	−132.3	0.7	0.6146
40.7438	−133.2	0.7	0.6254
40.7521	−131.4	0.5	0.6370
40.7604	−131.2	0.5	0.6487
40.7688	−130.1	0.5	0.6604
40.7792	−129.4	0.3	0.6750
40.7868	−128.9	0.4	0.6856
40.7952	−128.1	0.5	0.6974
40.8028	−127.3	0.4	0.7080
40.8111	−127.7	0.5	0.7197
40.8202	−124.9	0.5	0.7324
40.8278	−125.2	0.6	0.7431
40.8361	−124.5	0.6	0.7547
40.8445	−123.7	0.5	0.7664
40.8521	−124.4	0.7	0.7771
40.8604	−124.5	0.5	0.7887
40.8695	−125.8	0.5	0.8014
40.8799	−124.4	0.6	0.8160
40.8875	−128.5	0.6	0.8267
40.8959	−126.3	0.6	0.8384
40.9035	−132.5	0.6	0.8491
40.9118	−137.6	0.7	0.8607
40.9195	−146.4	0.6	0.8715
40.9278	−157.2	0.6	0.8831
40.9354	−159.9	0.6	0.8937
40.9438	−164.0	0.5	0.9055
40.9514	−163.6	0.7	0.9161
40.9591	−167.3	0.8	0.9269
40.9674	−170.0	0.7	0.9385
40.9757	−173.1	0.8	0.9502
43.7473	−127.7	0.6	0.8314
43.7563	−128.4	0.5	0.8441
43.7653	−135.4	0.6	0.8567
43.7736	−143.9	0.7	0.8683
43.7827	−150.6	0.7	0.8810
43.7910	−156.8	0.6	0.8926
43.8000	−161.7	0.8	0.9052
43.8090	−167.9	0.5	0.9178
43.8181	−171.3	0.7	0.9306
43.8313	−171.5	0.8	0.9491
43.8396	−174.3	0.7	0.9607
43.8486	−172.8	0.9	0.9733
43.8570	−175.4	0.9	0.9851
43.8660	−173.2	0.6	0.9977
43.8750	−173.3	0.5	0.0103

TABLE 1—*Continued*

J.D. (-2444700)	v_{rad}(km sec^{-1})	σ (km sec^{-1})	φ
43.8840	-168.8	0.6	0.0229
43.8931	-168.9	0.7	0.0356
43.9021	-170.6	0.6	0.0482
43.9111	-168.0	0.6	0.0608
43.9195	-168.4	1.2	0.0726
43.9292	-169.6	1.0	0.0862
43.9382	-168.7	1.1	0.0988
43.9472	-164.5	0.6	0.1114

with the 0.9 m telescope. The photometric and spectroscopic data were thus obtained simultaneously, and the problems of phasing the two sets of data were consequently overcome. The photometry technique involved a two-channel system and an 80/20 beam splitter. Eighty percent of the incoming light was directed to an S-11 photomultiplier equipped with *uvby* filters, and the remaining 20% was directed to an S-20 photomultiplier equipped with special *UBV* filters. Since the greatest need was for colors and magnitudes, only the *V* filter was used with the S-20, and most of the time only the *by* filters were used with the S-11. The constant use of the *V* filter allowed transformation to the standard *V* system (which is not as easily done with the *y* filter), and permitted proper monitoring of the $b-y$ colors during times of rapid magnitude and/or color changes. A 16″ diaphragm was used throughout the run to allow for variable seeing which is unavoidable when measures at high air masses ($X \sim 2.2$) are involved. Low air mass seeing generally varied from 1″ to 2″.5.

Repeated observations of two F stars near VY Ser were obtained to test for variable transparency and to determine the nightly extinction coefficients. The night of 1981 May 12/13 began cloudy and the skies did not clear until quite late, so only four measures of VY Ser and the comparisons were obtained, and no standards were observed. The nights of 13/14 and 14/15 were excellent, however, and VY Ser was observed almost continuously for about 7 hours each night. *Vby* extinction was monitored via the two comparison stars and three of the seven *uvbyV* standards, while extinction of the m_1 and c_1 indices was measured only via the three standards. The two nights had identical extinction, and the results are given in Table 2. To illustrate our successful treatment of extinction, we show in Figure 3 the resultant *V* magnitudes and $b-y$ colors for the two comparison stars for the two photometric nights.

The relatively large aperture of the telescope and concerns about saturation of the photomultiplier and discriminator ("dead-time corrections") led us to restrict our standard stars to those with $V \geq 5.0$ mag. Six stars with $-0.05 \text{ mag} \leq b-y \leq +0.64$ mag were selected from the lists of Crawford and Barnes (1970) and Grønbech, Olsen, and Strömgren (1976). HR 4409, a standard in Eggen's (1976, 1978) modified *uvby* system, was added for *V* and $b-y$ calibration since the Strömgren and Eggen systems are identical for $b-y$ colors. Linear transforma-

TABLE 2

CTIO Extinction Measures

Extinction Coefficient	Value (mag) 13/14	14/15	Sources[a]
k_v	0.122 ± 0.004	0.137 ± 0.004	S, C
k_{b-y}	0.051 ± 0.002	0.054 ± 0.003	S, C
k_{m_1}	0.061 ± 0.005	0.059 ± 0.004	S
k_{c_1}	0.138 ± 0.020	0.136 ± 0.004	S

[a] S = standard, C = comparison stars.

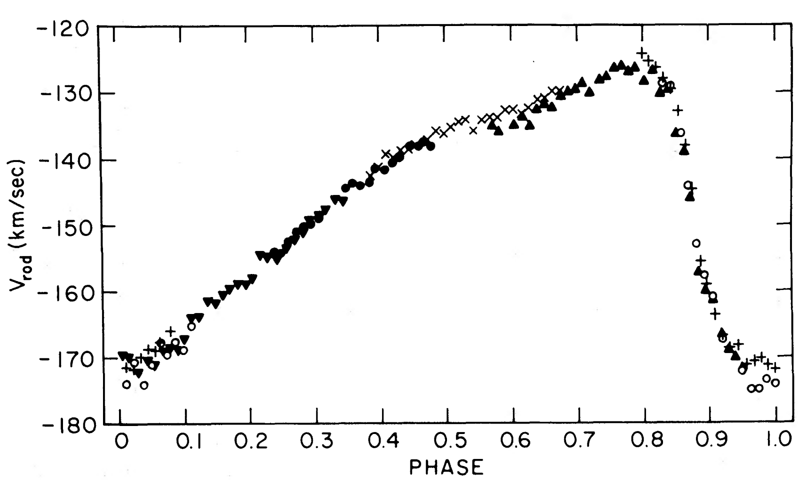

Fig. 2.—The radial velocities of Table 1 plotted against phase, using JD 2,444,738.869 as $\phi = 0.00$. The symbols refer to data obtained on the following nights in 1982 May: 11/12 (▼); 12/13 (×); 13/14 (+); 14/15 (●); 15/16 (▲); and 18/19 (○).

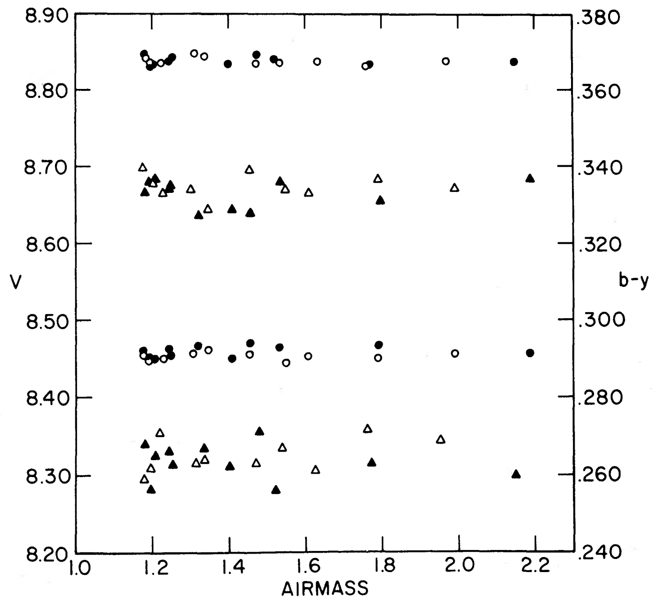

FIG. 3.—The derived V and $(b-y)$ values for the two comparison stars in Table 3 as a function of airmass. Symbols are: ● = V magnitudes of stars A and B on May 13/14; ○ = V magnitudes on May 14/15; ▲ = $(b-y)$ colors of stars A and B on May 13/14; △ = $(b-y)$ colors on May 14/15.

tions of the natural $b-y$, m_1, and c_1 indices into standard values were performed, and the V magnitude was obtained via:

$$V = v_0 + \epsilon(b-y)_0 + \zeta_v \,. \tag{2}$$

The errors of the mean for each index were: V (± 0.005 mag); $b-y$ (± 0.002 mag); m_1 (± 0.007 mag); and c_1 (± 0.10 mag). The results for the two comparison stars are given in Table 3, where the quoted errors are only the internal errors and do not include the errors given above.

The four observations of VY Ser on the night of 1981 May 12/13 were transformed to the standard system via the comparison star values given in Table 3. The final photometric results, arranged by Julian date and including the phase

TABLE 3

COMPARISON STARS

Parameter	A HD 138041 BD +2° 2967	B HD 138076 BD +2° 2968
Spectral type (HD)	F2	F6
$V/\sigma/n$ (mag)	8.839/0.001/21	8.456/0.001/21
$(b-y)/\sigma/n$ (mag)	0.264/0.001/21	0.334/0.001/21
$m_1/\sigma/n$ (mag)	0.148/0.005/4	0.180/0.004/4
$c_1/\sigma/n$ (mag)	0.657/0.005/4	0.450/0.004/4

computed as discussed previously (eq. [1] -0.016), are given in Table 4 and plotted in Figures 4 and 5, with the same symbols for various nights as in Figure 2. Note the "premaximum pause" at $\phi \sim 0.9$. This is often seen in the rising light curves of novae, and both presumably arise from an opacity change.

III. METHODS OF ANALYSIS

Following the original suggestion of the technique by Baade (1926), Wesselink (1969) introduced the use of the visual surface brightness, S_v, as a means of determining pulsating stars' radii and distances. McDonald (1977) employed this version of the method after obtaining intermediate-band photometry for 25 halo variables (plus many disk variables as well). His method was a significant improvement because it incorporated the metal sensitivity of the color-temperature relation. Siegel (1980) then further improved the method by incorporating the gravity sensitivity of the colors, following the lead of McNamara and Feltz (1977). Most recently, Manduca *et al.* (1981) employed the thorough reevaluation of S_v due to Manduca and Bell (1981). In spite of the significant advancements made in the methodology discussed above, all of the above investigations suffer from two major observational handicaps. First, for metal-poor, fundamental mode (i.e., larger amplitude) RR Lyraes, only three satisfactory radial velocity curves exist: RR Lyr (Struve and Blaauw 1948; Sanford 1949), X Ari (Oke 1966), and SU Dra (Oke, Giver, and Searle 1962;

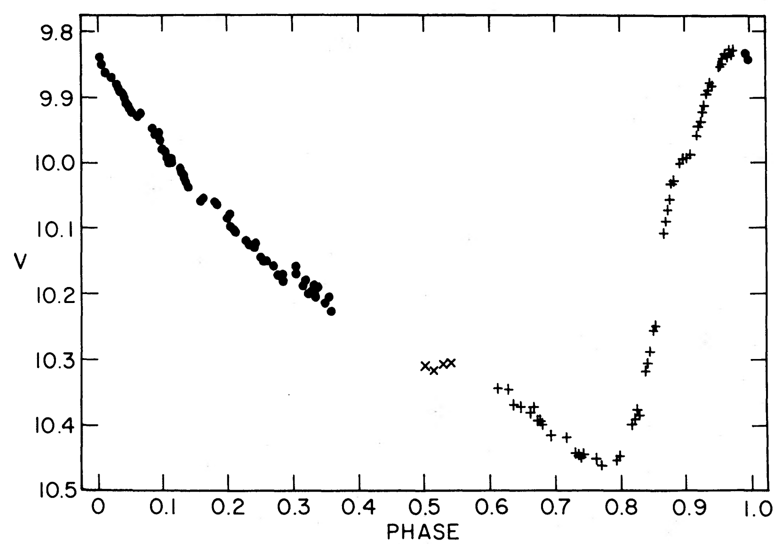

FIG. 4.—V magnitudes of VY Ser from Table 4. Same symbols and phases as Fig. 2.

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TABLE 4

PHOTOMETRIC DATA

J.D.(-2444700)	φ	V	b-y	m_1	c_1
37.7992	0.5019	10.310	0.356		
37.8088	0.5153	10.317	0.336		
37.8177	0.5278	10.307	0.343		
37.8265	0.5401	10.307	0.342		
38.5917	0.6117	10.345	0.341		
38.6033	0.6279	10.346	0.338		
38.6092	0.6362	10.368	0.344		
38.6179	0.6484	10.371	0.332		
38.6277	0.6621	10.380	0.337		
38.6314	0.6673	10.373	0.344		
38.6357	0.6733	10.393	0.342		
38.6380	0.6765	10.394	0.327		
38.6399	0.6792	10.396	0.327		
38.6498	0.6930	10.415	0.337		
38.6662	0.7160	10.417	0.335		
38.6767	0.7307	10.440	0.351		
38.6796	0.7348	10.441	0.342		
38.6818	0.7378	10.446	0.342		
38.6842	0.7412	10.444	0.348		
38.7000	0.7633	10.451	0.343	0.066	0.725
38.7048	0.7701	10.460	0.346	0.058	0.712
38.7209	0.7926	10.452	0.342	0.058	0.669
38.7257	0.7993	10.446	0.337	0.063	0.684
38.7386	0.8174	10.398	0.329		
38.7416	0.8216	10.388	0.334		
38.7437	0.8245	10.376	0.327		
38.7454	0.8269	10.384	0.325		
38.7535	0.8383	10.319	0.310		
38.7562	0.8420	10.306	0.303		
38.7583	0.8450	10.288	0.299	0.076	0.845
38.7622	0.8504	10.256	0.296		
38.7638	0.8527	10.247	0.305		
38.7736	0.8664	10.108	0.277		
38.7764	0.8703	10.089	0.271		
38.7786	0.8734	10.073	0.274		
38.7807	0.8763	10.056	0.266		
38.7824	0.8787	10.033	0.259		
38.7850	0.8824	10.029	0.264		
38.7918	0.8919	10.001	0.245		
38.7939	0.8948	9.999	0.243		
38.7957	0.8974	9.995	0.251		
38.7989	0.9018	9.993	0.245	0.063	0.923
38.8028	0.9073	9.988	0.246		
38.8097	0.9170	9.959	0.237		
38.8119	0.9200	9.944	0.226		
38.8141	0.9231	9.938	0.227		
38.8162	0.9261	9.924	0.219		
38.8183	0.9290	9.913	0.228		
38.8212	0.9331	9.896	0.223		
38.8234	0.9361	9.889	0.214		
38.8255	0.9391	9.878	0.220		
38.8276	0.9420	9.880	0.207		
38.8351	0.9525	9.852	0.209		
38.8373	0.9556	9.851	0.198		
38.8394	0.9585	9.841	0.210		
38.8422	0.9625	9.835	0.214		
38.8443	0.9654	9.835	0.214		
38.8465	0.9685	9.827	0.201		
38.8486	0.9714	9.836	0.208		
38.8506	0.9742	9.828	0.209		
39.5793	0.9947	9.832	0.199		
39.5820	0.9985	9.839	0.201		
39.5842	0.0015	9.840	0.215		
39.5870	0.0055	9.848	0.204		
39.5914	0.0116	9.860	0.215		
39.5985	0.0216	9.868	0.222		
39.6035	0.0286	9.877	0.226		
39.6056	0.0315	9.885	0.221		
39.6078	0.0346	9.892	0.225		
39.6095	0.0370	9.889	0.228		
39.6123	0.0409	9.899	0.224		
39.6144	0.0438	9.907	0.234		
39.6164	0.0466	9.911	0.234		
39.6187	0.0499	9.916	0.229		

TABLE 4—*Continued*

J.D.(-2444700)	ϕ	V	b-y	m_1	c_1
39.6203	0.0521	9.923	0.238		
39.6284	0.0634	9.927	0.239		
39.6300	0.0657	9.925	0.246		
39.6435	0.0846	9.947	0.237		
39.6466	0.0889	9.957	0.253		
39.6483	0.0913	9.957	0.249		
39.6500	0.0937	9.953	0.261		
39.6527	0.0975	9.966	0.252		
39.6546	0.1001	9.981	0.251		
39.6568	0.1032	9.982	0.257		
39.6583	0.1053	9.991	0.262		
39.6613	0.1095	9.998	0.247		
39.6630	0.1119	9.992	0.253		
39.6644	0.1139	9.998	0.264		
39.6729	0.1258	10.007	0.268		
39.6747	0.1283	10.011	0.260		
39.6769	0.1314	10.017	0.271		
39.6788	0.1340	10.024	0.271		
39.6806	0.1365	10.025	0.271		
39.6829	0.1398	10.036	0.275	0.046	0.978
39.6956	0.1575	10.056	0.271		
39.6970	0.1595	10.054	0.292		
39.7117	0.1801	10.061	0.284		
39.7142	0.1836	10.062	0.286		
39.7257	0.1997	10.082	0.288		
39.7281	0.2031	10.078	0.291		
39.7301	0.2059	10.097	0.290		
39.7320	0.2085	10.100	0.286		
39.7334	0.2105	10.103	0.294		
39.7459	0.2280	10.118	0.306		
39.7477	0.2305	10.122	0.302		
39.7494	0.2329	10.124	0.303		
39.7509	0.2350	10.126	0.310		
39.7538	0.2391	10.127	0.301		
39.7557	0.2417	10.129	0.304		
39.7575	0.2442	10.124	0.306		
39.7632	0.2522	10.144	0.313		
39.7649	0.2546	10.151	0.308		
39.7663	0.2566	10.150	0.311		
39.7693	0.2608	10.150	0.311		
39.7773	0.2720	10.161	0.312		
39.7832	0.2802	10.172	0.318		
39.7850	0.2827	10.171	0.322		
39.7863	0.2846	10.180	0.319		
39.8001	0.3039	10.160	0.312		
39.8015	0.3058	10.168	0.332		
39.8095	0.3171	10.190	0.313		
39.8115	0.3199	10.180	0.329		
39.8131	0.3221	10.199	0.323		
39.8158	0.3259	10.197	0.331		
39.8179	0.3288	10.198	0.334		
39.8200	0.3318	10.188	0.332		
39.8221	0.3347	10.203	0.323		
39.8237	0.3369	10.189	0.330		
39.8324	0.3491	10.214	0.333		
39.8346	0.3522	10.206	0.349		
39.8371	0.3557	10.228	0.334		

Preston 1965). Second, such data were obtained many years prior to the photometric studies, and hence there is a question of relative phasing of the two sets of data. The phasing has been generally accomplished by use of the published ephemerides and some small but nonzero phase shift, justified in part by the limited accuracy of the published periods and their stability. In no previous case, then, have the photometry and spectroscopy been obtained simultaneously. We also note that Woolley and Savage (1971) and McDonald (1977) employed a mean radial velocity curve for all their variables which is improper and will bias their results toward finding similar values for $\langle M_v \rangle_{RR}$. Among the metal-poor variables, Siegel (1980) studied only SU Dra and RR Lyr while Manduca *et al.* (1981) studied only X Ari and RR Lyr. Since RR Lyr shows a strong Blazhko effect and has the most serious spectroscopic-photometric time differential and consequent phasing uncertainty, we see that much work could be profitably done on field stars alone. This paper deals with

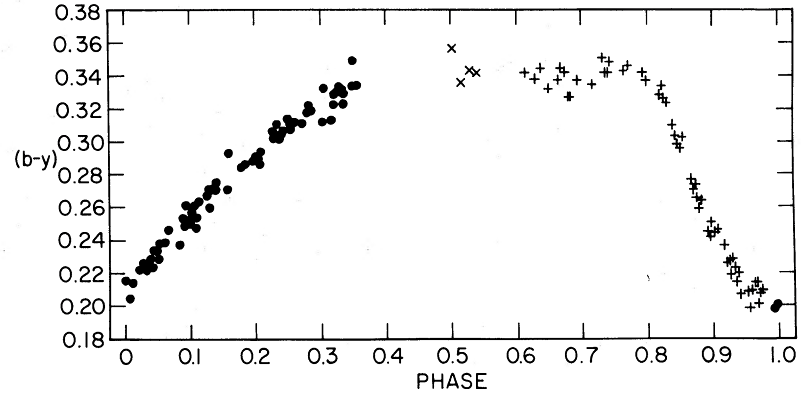

FIG. 5.—$(b-y)$ colors of VY Ser from Table 4. Same symbols and phases as Fig. 2.

data for a star not known to show the Blazhko effect, and, with the simultaneous radial velocity and photometric observations, we have circumvented most of the observational difficulties. The analysis will be carried out using two versions of the Baade-Wesselink method, both of which employ model atmospheres to correct for metallicity and gravity effects on the colors and magnitudes in order to better determine temperatures and luminosities.

a) *The Algebraic Method*

The heart of the Baade-Wesselink method is the relation between the "spectroscopic radii," $\Delta R_{\rm spec}$, and the "photometric radii" at any two phases. The former follows from integrating the pulsational velocity curve from the first phase to the second, and is hence derived from the radial velocity curve. The second is related to the ratio $(l_{\rm phot})^{1/2}T^{-2}$, and both the luminosity and temperature follow in principle from magnitudes and colors. Distances are derived by comparing the linear difference in radii from $\Delta R_{\rm spec}$ to the ratio of angular radii from the photometry.

If v_p is the pulsational velocity, $v_{\rm rad}$ the observed radial velocity, and γ the systematic velocity, then $\Delta R_{\rm spec}$ between any two phases ϕ_1 and ϕ_2 is:

$$R(\phi_2) - R(\phi_1) = \Delta R_{\rm spec}(\phi_1, \phi_2) = -\int_{\phi_1}^{\phi_2} v_p\,dt = -\int_{\phi_1}^{\phi_2} p(v_{\rm rad} - \gamma)dt\,, \qquad (3)$$

where p is a correction factor necessary to account for the convolved line profiles from an integrated spherical stellar atmosphere. For a gray atmosphere undergoing uniform expansion, $p = 24/17 = 1.41$ (Wesselink 1946*a*, *b*; Rosseland 1964). Karp's (1975) work on classical Cepheids yielded $p = 1.35$, while Castor (1966) used hydrodynamic models of RR Lyraes to find $p = 1.33$. Parsons (1972) found the inclusion of instrumental broadening to be a significant effect, and at 10 Å mm^{-1} dispersions characteristic of coudé spectrographs he obtained $p = 1.31$. At the higher resolution of our observations, we expect p to slightly decrease, and we will adopt $p = 1.30$.

The systemic velocity follows directly from integrating the radial velocity data from $\phi = 0$ to 1, from which we find $\gamma = -146.9$ km s^{-1}. Similarly, we find $\langle V \rangle_0 = 10.09$ mag and $\langle b-y \rangle_0 = 0.280$ mag after allowing for our adopted reddening of $E(B-V) = 0.03$ mag.

Let us define $r(\phi_1, \phi_2)$ to be the ratio of the "photometric radii":

$$r(\phi_1, \phi_2) = \frac{R_{\rm phot}(\phi_2)}{R_{\rm phot}(\phi_1)} = \left[\frac{T_{\rm eff}(\phi_1)}{T_{\rm eff}(\phi_2)}\right]^2 {\rm dex}\,\{-0.2[m_{\rm bol}(\phi_2) - m_{\rm bol}(\phi_1)]\}\,. \qquad (4)$$

We are confronted, then, with transforming our apparent visual magnitudes and colors into apparent bolometric magnitudes and effective temperatures. Synthetic bolometric corrections and *UBV*, *uvby* colors have been computed by Kurucz (1979, 1980) using atomic line-blanketed model atmospheres with a very wide range of temperatures, gravities, and metallicities. We have chosen to work with his unpublished results, which differ from those of Kurucz (1979) only in the adopted strength of convection. The earlier results (Kurucz 1979) used $\alpha = 2$ ($\alpha \equiv$ the ratio of convective mixing length to pressure scale height), whereas our adopted colors were computed from $\alpha = 1$ models. The zero points of the synthetic colors pose a problem, for the Sun has the best determined luminosity and temperature, but the least accurate colors. Hence we choose to set the zero points via Procyon, as discussed by Carney and Jones (1983). Procyon has a well determined effective temperature and radius ($T_{\rm eff} = 6510 \pm 130$ K; $\log R/R_\odot = 0.317 \pm 0.016$; Code *et al.* 1976), mass ($\log M/M_\odot = 0.25$; Harris 1963), and consequently a known surface gravity, $\log g \sim 4.1$. The $\alpha = 1$ Kurucz models predict $(b-y)_0 = 0.275 \pm 0.017$ mag for such a star ([metals/H] = 0), whereas the observed value is 0.272 mag (Hauck and Mermilliod 1979). Given this excellent agreement and that VY Ser has colors very similar to Procyon ($\langle b-y \rangle_0 = 0.280$ mag), we adopt the synthetic colors with no zero-point shift. Since [Fe/H] = -1.8 for VY Ser (Carney and Jones 1983), we interpolate in the [metals/H] = -1.5 and -2.0 model colors to produce the variation of $b-y$ with temperature and gravity given in Table 5. For the variations of bolometric corrections with temperature and gravity, we adopt a zero-point shift of $+0.240$ mag. This produces a bolometric correction for Procyon's model of -0.015 mag, compared to the observed value of -0.02 ± 0.05 mag (Code *et al.* 1976, based on a solar value of -0.07 mag) and a solar model atmosphere bolometric correction of -0.10 mag. The zero points drop out

TABLE 5

SYNTHETIC COLORS AND BOLOMETRIC CORRECTIONS (B.C.)

log g	EFFECTIVE TEMPERATURE (K) 5500	6000	6500	7000	7500
0.0:					
$b-y$	0.408	0.279	0.160	0.100	0.087
B.C.	−0.110	−0.005	+0.044	+0.074	+0.060
0.5:					
$b-y$	0.399	0.285	0.180	0.105	0.087
B.C.	−0.125	−0.023	+0.036	+0.063	+0.057
1.0:					
$b-y$	0.394	0.290	0.199	0.110	0.064
B.C.	−0.142	−0.042	+0.024	+0.052	+0.052
1.5:					
$b-y$	0.391	0.296	0.212	0.128	0.066
B.C.	−0.159	−0.063	+0.004	+0.041	+0.044
2.0:					
$b-y$	0.391	0.303	0.225	0.151	0.077
B.C.	−0.176	−0.087	−0.019	+0.025	+0.031
2.5:					
$b-y$	0.392	0.310	0.237	0.169	0.098
B.C.	−0.193	−0.110	−0.046	+0.000	+0.015
3.0:					
$b-y$	0.395	0.318	0.249	0.184	0.123
B.C.	−0.207	−0.133	−0.075	−0.029	−0.005
3.5:					
$b-y$	0.398	0.325	0.260	0.199	0.142
B.C.	−0.216	−0.152	−0.102	−0.061	−0.034
4.0:					
$b-y$	0.403	0.332	0.270	0.213	0.158
B.C.	−0.220	−0.166	−0.127	−0.093	−0.068

in the computation of the radii because we are dealing only with differences in bolometric corrections, but for the derivation of distances via intrinsic luminosities they are required.

From equations (3) and (4), the radii at phases ϕ_1 and ϕ_2 may be found by:

$$R(\phi_1) = \Delta R_{\rm spec}(\phi_1, \phi_2)/[r(\phi_1, \phi_2) - 1] , \quad (5)$$

and

$$R(\phi_2) = R(\phi_1) + \Delta R_{\rm spec}(\phi_1, \phi_2) . \quad (6)$$

The only remaining question is that of the appropriate gravity. We could, as Siegel (1980) did, use the Strömgren c_1 index. We decided, however, not to follow his example because it requires well over twice as much telescope time to obtain full *uvby* data compared to simple $b-y$ colors, and because the c_1 versus log g results typically still show rather large scatter. We judged our goals would be better achieved by careful monitoring of $b-y$, whose transformation to effective temperature only secondarily depends on gravity. Therefore in our analysis we adopt a stellar mass of 0.6 $M_\odot$ (the results are insensitive to this choice), and adopt a first choice of log g at $\phi = 0$ (usually log $g = 2.5$, based on the results of Carney and Jones 1983). A mean value for the radius at $\phi = 0$ is then computed by averaging over equation (5) for many later phases:

$$\langle R_{\phi=0} \rangle = \left\langle \frac{\Delta R_{\rm spec}(\phi = 0, \phi > 0)}{r(\phi = 0, \phi > 0) - 1} \right\rangle_\phi . \quad (7)$$

This new value for $R(\phi = 0)$ yields a new estimate of log g at $\phi = 0$, and the iterations continue until convergence is achieved (two or three iterations are sufficient). Gravities at phases other than zero are computed via equation (6), which yields the appropriate radii, and from

$$\log g_{\rm eff} = \log \left[\frac{GM}{R^2} + \frac{d^2R}{dt^2}\right] . \quad (8)$$

Since d^2R/dt^2 is just $d(v_p)/dt$, we only need to numerically differentiate the pulsational velocity curve, which we accomplish via

$$\frac{d^2R}{dt^2}(\phi_n) = \frac{v_p(\phi_{n-2}) - 6v_p(\phi_{n-1}) + 6v_p(\phi_{n+1}) - v_p(\phi_{n+2})}{8h} , \quad (9)$$

where h is the phase interval, and is chosen to be 0.01 since we have smoothed the observational data into 0.01 × period bins prior to the analysis.

We do not compute the value for $R(\phi = 0)$ using all the later phases. Equations (4) and (5) reveal potential numerical difficulties when $R(\phi_1) = R(\phi_2)$, and we choose to partially avoid such a problem by computing $R(\phi = 0)$ using data only from phases $\phi = 0.01$ to 0.30. The radius curve derived from Figure 2 and equation (3) reveals that during this interval the star expands from near minimum to near maximum radius, as depicted in Figure 6. For numerical accuracy alone, we should expand the phase interval to some time just *before* $R(\phi) = R(\phi = 0)$, or to about $\phi \sim 0.7$. However, we also wish to numerically check for phase problems involving the spectroscopic and photometric radii. The observational uncertainties in the phasing have been overcome, as we have already mentioned, but such an effect could still be present and we must be prepared to test for it. Consequently, we computed $R(\phi = 0)$ based on data for $\phi = 0$ to 0.3, then from 0 to 0.75, and finally, from 0 to 1. In each case we iterated several times to achieve convergence. Similar values of $R(\phi = 0)$ from each of the three phase intervals would indicate the lack of phasing problems; conversely, discordant results would signify serious phasing difficulties.

b) Surface Brightness Method

The technique devised by Wesselink (1969) has been most recently discussed and reformulated by Manduca and Bell (1981) and Manduca *et al.* (1981). Briefly, one may readily derive the following relation between unreddened apparent visual magnitude V_0, bolometric correction B.C., angular diameter θ_0 (in milli-arcseconds), and effective temperature, $T_{\rm eff}$:

$$V_0 + \text{B.C.} + 5 \log \theta_0 + 10 \log T_{\rm eff} = \text{constant} . \quad (10)$$

We define a visual surface brightness, S_v:

$$S_v = V_0 + 5 \log \theta_0 = \text{constant} - \text{B.C.} - 10 \log T_{\rm eff} . \quad (11)$$

The calibration of the constant proceeds, as before, with observed magnitudes, bolometric corrections, angular diameters, and effective temperatures. The results of Code *et al.* (1976) for Procyon, α Aql, and α Oph yield a constant of 42.187 with an error of ±0.090 due to observational uncertainties. If we instead use the observed colors and gravities of the three stars and Kurucz's synthetic colors to obtain temperatures and bolometric corrections, we find a constant of 42.153

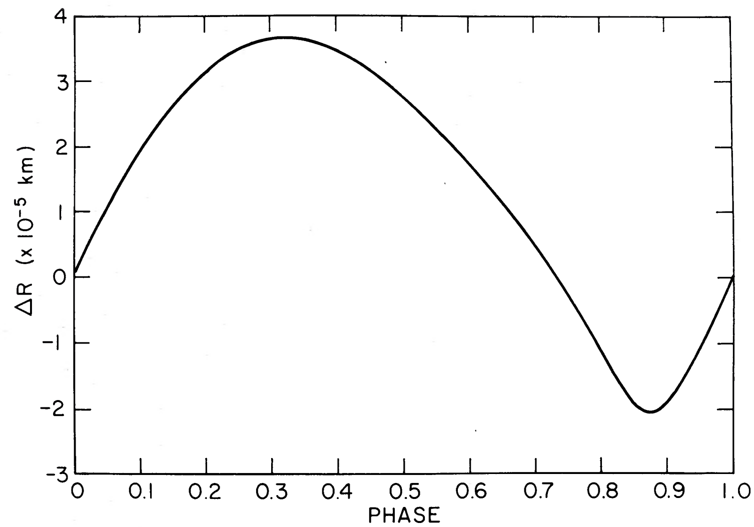

FIG. 6.—The difference in linear radius between various phases and $\phi = 0.00$, obtained from Table 1, eq. (3), and the phasing of Fig. 2

$\pm$ 0.053. We choose not to use the Sun in the calibration due to its uncertain V magnitude. We adopt a constant value of 42.160. Observed colors of VY Ser, and gravities inferred from equation (8), yield effective temperatures and bolometric corrections, and from observed magnitudes we obtain "photometric angular diameters," $\theta_{\rm phot}$, via equation (10). We plot these results against the "spectroscopic angular diameters," $\theta_{\rm spec}$, whose values will depend on the initial radius, equation (3), and the distance. The photometric angular diameter $\theta_{\rm phot}$ will also depend to some degree on the initial radius because of the gravity sensitivity of the colors and magnitudes. Comparison of the plots of $\theta_{\rm phot}$ and $\theta_{\rm spec}$ will yield a best choice of the star's distance as well as $R(\phi = 0)$ in the absence of phasing problems. The method demands more graphics than the algebraic method, but its virtues are significant: distance is readily obtained, and phase differences are more obvious. Further, it is less prone to the potential numerical difficulties of the algebraic method discussed above.

IV. RESULTS

We have compared our radial velocity curve of VY Ser (Fig. 1) to those of SU Dra (Oke, Giver, and Searle 1962; Preston 1965) and X Ari (Oke 1966) to test their assumed (Woolley and Savage 1971; McDonald 1977) equality. We disregard RR Lyr because of its variable pulsation amplitude. The three stars have similar periods ($0^{\rm d}.714$, $0^{\rm d}.66$, and $0^{\rm d}.65$) and are all metal-poor ($\Delta S = 9$, 9.6, and 11.7). The relative maximum and minimum velocities are reached at nearly identical phases for the three stars, but the radial velocity amplitudes are noticeably different: 49 km s^{-1} (VY Ser), ≥ 58 km s^{-1} (SU Dra), and 55 km s^{-1} (X Ari). The assumption that $\Delta v_{\rm rad}$ is 57 km s^{-1} for all RR*ab* stars (Woolley and Aly 1966) is therefore incorrect. The use of a relation between radial velocity amplitude and visual magnitude amplitude, Δm_v, of the form

$$\Delta v_{\rm rad} = a \Delta m_v + b \tag{12}$$

may be justified, however. With $\Delta m_v \sim 0.69$ mag (VY Ser), 1.00 mag (SU Dra), and 0.95 mag (X Ari), we find $a \sim 27$ km s^{-1} mag^{-1} and $b \sim 30$ km s^{-1}. A relation (McDonald 1977) between $\Delta v_{\rm rad}$ and period may also be justified, for we see that, for these three stars,

$$\Delta v_{\rm rad} \sim -118 P(\text{days}) + 134 \text{ km s}^{-1} , \tag{13}$$

which is a much steeper relation than that adopted by McDonald (1977), and suggests his conclusion that $\langle M_v \rangle_{\rm RR}$ is constant and independent of metallicity might require revision.

Before applying our methods to VY Ser, we used the photometric data for X Ari of Manduca *et al.* (1981) and the radial velocities of Oke (1966). For both the surface brightness and algebraic methods, we found the same value of $\langle M_v \rangle_{\rm RR}$ for X Ari as found by Manduca *et al.* (1981), to within 0.1 mag. Further, no phase shifts were required, even though the photometric and spectroscopic data were obtained over a decade apart.

Our major result for VY Ser is obtained using both the algebraic and S_v methods: there is a serious phase shift problem. The algebraic method yielded $\langle M_v \rangle_{\rm RR}$ values of 1.90, 2.63, and 4.49 mag for the phase intervals 0–0.3, 0–0.75, and 0–1, respectively, while Figure 7 shows that $\theta_{\rm spec}$ clearly leads $\theta_{\rm phot}$. We chose log g at $\phi = 0$ so that the mean values of the angular diameters matched, and the distance was chosen so that the amplitudes of the angular diameter variations matched. We show two $\theta_{\rm spec}$ curves, appropriate to $m - M = 8.60$ and 8.65 mag, to demonstrate the sensitivity of the data to the assumed distance modulus. The phase shift required to bring about agreement between $\theta_{\rm spec}$ and $\theta_{\rm phot}$ for both the algebraic and S_v methods is $\Delta\phi \sim 0.075$, or about $1^{\rm h}17^{\rm m}$. A simple constant phase shift of this order is not likely to yield proper results, but it is worth repeating the calculations to see what the effects are. The algebraic method then yields $\langle M_v \rangle_{\rm RR} = 1.69$, 1.63, and 1.69 mag for the three phase intervals, while Figure 8 displays the S_v results after the radial velocities have been shifted by $\Delta\phi = 0.08$. In this case, log $g(\phi = 0) \sim 3.10$ and $\langle M_v \rangle_{\rm RR} \sim +1.45$ mag.

The existence of the phasing problem in VY Ser is potentially critical since the observational phasing problems have already been eliminated. It is particularly important, therefore, to

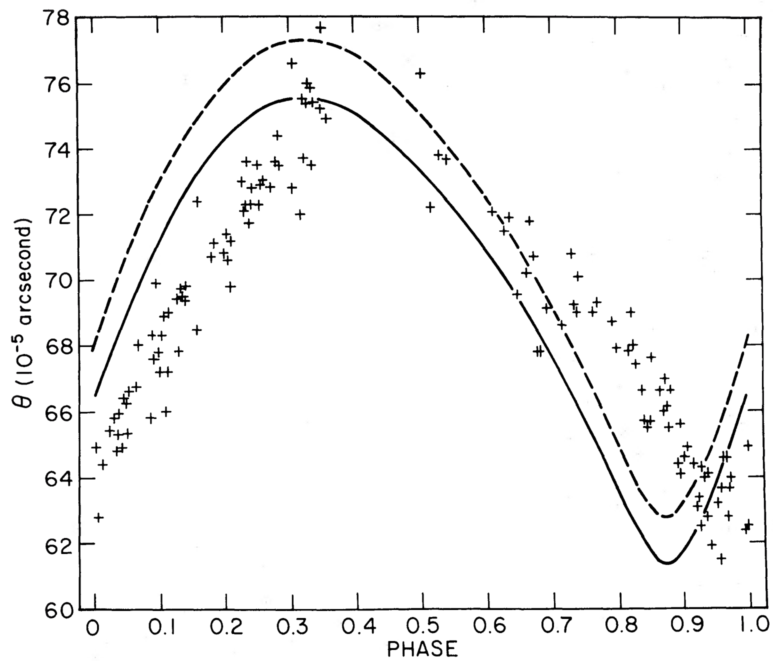

FIG. 7.—The angular diameters (units are 10^{-5} arcsec) obtained via the S_v method and the data of Tables 1 and 4. + = "photometric radii" (eqs. [10] and [11]); ---- = "spectroscopic radii" with $m-M = 8.60$ mag; —— = "spectroscopic radii" with $m-M = 8.65$ mag. Log $g(\phi = 0) = 3.05$.

identify the cause of the failure of the Baade-Wesselink method for VY Ser and to see if it is likely to be "global" so that we cannot work with any other stars, or if it is "local" and due to VY Ser alone.

One possible explanation is that the spectroscopic and photometric data are sampling different depths of the stellar photosphere and that these depths are slightly out of phase. In the simplest case, the phase separation would be constant and we could apply whatever shift is necessary to bring θ_{spec} and θ_{phot} into agreement. We feel that, in the case of VY Ser at least, this solution is inadmissible. For example, the effective gravity at $\phi = 0$ is about 3.0–3.1 according to the analysis, but the spectroscopic gravity determined by Carney and Jones (1983) is very much lower, log $g \sim 2.2$. The faint value of $\langle M_v \rangle_{\text{RR}}$ found in our study might reduce the kinematical properties of the star to less extreme levels, but if applicable

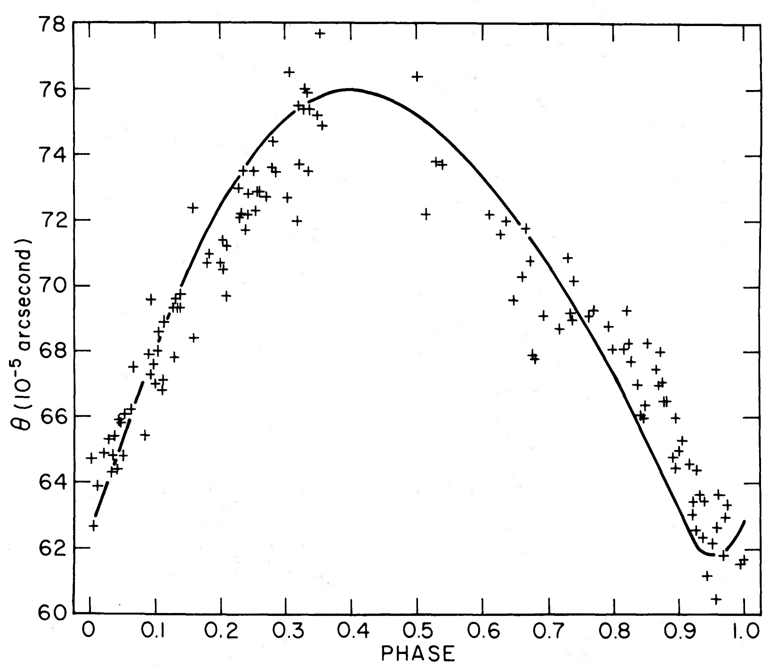

FIG. 8.—Same as Fig. 7, but with log $g(\phi = 0) = 3.10$, $m-M = 8.65$ mag, and a phase shift $\Delta\phi = 0.08$ applied to the radial velocity data

to globular cluster variables, the turnoff luminosities would be so faint that the clusters' ages and helium abundances would be incredibly large. Finally, as McDonald (1977) has pointed out, according to model atmospheric calculations, the separation between the line-forming and continuum-forming regions is only about 10^4 km, which is very small compared to the radius variation of $\sim 5.6 \times 10^5$ km. The speed of sound is also high enough that phase differences exceeding 20 minutes would be quickly eliminated. Unlikely though we feel this mechanism to be, it might be worth studying. Short-exposure, high-resolution spectrograms could be used to study the radial velocity versus depth as a function of phase since weak, high-excitation lines will form considerably deeper than stronger, lower excitation lines.

We suspect our results apply only to VY Ser and do not necessarily imply the "global" failure of the Baade-Wesselink method in its application to RR Lyrae variables. The excellent results of Manduca *et al.* (1981), for example, indicate that the method works for at least some stars. What is it, then, that differentiates VY Ser from X Ari, SU Dra, or other RR Lyraes? Presumably, it is some phenomenon that systematically distorts either the radial velocities or the colors and magnitudes or both.

The radial velocities are unlikely to be at fault. It has long been known, of course (Sanford 1949), that the metal and hydrogen lines display different radial velocity curves. During rising light, in fact, some of the Balmer lines reveal emission behavior, which is to be expected from the shocks that form at the low densities in which the Balmer lines form. Our velocities, however, are based on much weaker metal lines which form much closer to the photosphere and should not be susceptible to such a phenomenon. An undetected binary could, of course, distort radial velocities, but we point out that the echelle spectrogram obtained near minimum light by Carney and Jones (1983) showed no signs of a second set of spectral lines, and the cross-correlation technique never showed any evidence for a second set of lines either. Further, the velocities are seen in Figure 1 to be repeatable over several cycles.

Perhaps because of its inclination or a wide separation, a faint binary might not affect the radial velocities, but it could still distort the colors and magnitudes of VY Ser as it brightens and fades. The color sensitivity is the most promising avenue to follow, since a star with similar color will only aggravate the problem because its removal would make the apparent magnitudes even fainter and consequently make $\langle M_v \rangle_{\rm RR}$ fainter as well. We have experimented with the effects due to a binary by subtracting a variety of stars from our data. Each has a constant brightness and differs from the mean VY Ser magnitude and color by some arbitrary amount. Because we have not seen any stars more than about 0''.3 from VY Ser, we assume this companion is physically associated, and we therefore use secondaries appropriate to the globular cluster M3, which has a metallicity very similar to VY Ser ([Fe/H = −1.68: Cohen 1978; Pilachowski, Wallerstein, and Leep 1980). Fainter and redder companions slightly ease the phasing and the derived $\langle M_v \rangle_{\rm RR}$ values, but not by an amount even close to solving the problem. In fact, it does not appear any secondary can remove the phase problem.

There is one more possible source of color distortion which might be at work: convection. The evidence we will present here is circumstantial at best, but taken together it encourages us that the problem rests with VY Ser and we should be able to avoid it in the future. VY Ser differs from most other field RR Lyraes that have been studied to date in that it is the coolest, with $\langle T_{\rm eff} \rangle = 6200$ K. As Deupree (1977) has discussed, the cool edge of the instability strip is likely determined by the damping effects of convection, and VY Ser lies near the red edge. For example, in M3 the red edge lies at $\langle B-V \rangle_0 = 0.42$ mag (Sandage 1969, 1981*b*), and VY Ser has $\langle B-V \rangle_0 = 0.37$ mag (Varsavsky 1960). If convection is present, how is it likely to manifest itself? First, we might expect to see signs of higher turbulent velocities derived from high-resolution spectroscopy, and Carney and Jones (1983) did in fact see such an effect. They found a "microturbulent" velocity of 4.2 km s^{-1}, which is notably higher than values found by Butler and Deming (1979) in their analyses of several field RR Lyraes, and by Caldwell and Butler (1978) in their analysis of BL Her, a slightly hotter and more luminous variable. A study of microturbulent velocities as a function of mean effective temperature might be very profitable if conducted with the same spectroscopic equipment and with highest resolution.

A second signature of convection might be in the manner of its color distortions. Dennis (1968) pointed out that when convection penetrates to near the continuum-forming region, the colors will become systematically bluer. This was reiterated by Bessell and Wickramasinghe (1979) in their study of the halo K dwarfs with extreme ultraviolet excesses. Among dwarfs, such effects of convection should not appear until $T_{\rm eff}$ has dropped to 5000 K or less (Carney 1980). In the RR Lyrae variables, however, convection could become important at higher temperatures because of the atmospheric dynamics. We at least know to look for a tendency for colors to become too blue when convection is present near the continuum-forming layers. There are two suggestions of such effects in RR Lyraes. First, Manduca (1982) has mentioned that when Manduca and Bell (1981) attempted to fit the $\theta_{\rm spec}$ results for RR Lyr using Siegel's (1980) *uvby* data, they required a phase shift about as large as that found here for VY Ser. However, a much smaller shift was needed when they used $V-R$ colors, which suggests the blue colors were more strongly affected, as expected from convection. Second, if we apply the simple phase shift $\Delta\phi = 0.08$ and look at the result seen in Figure 8, we notice that $\theta_{\rm phot}$ deviates from $\theta_{\rm spec}$ in a systematic fashion, being higher when the radius is smaller than the mean and smaller when the radius is greater than the mean. If convection is the culprit, its effects should be strongest when the temperatures are at their lowest, for that is when convection will be strongest. The temperatures are lowest from phases 0.3–0.7, approximately (Fig. 5), and if convection is especially strong during that phase interval, then we should see colors that are systematically too blue, and from equations (10) and (11) the resultant overestimate of the temperatures will produce an underestimate of the photometric angular diameters, $\theta_{\rm phot}$, which is exactly what we see in this phase interval in Figure 8.

We conclude that VY Ser is probably too susceptible to the effects of convection because of its cool temperatures, and that our selection of a blue index to monitor the temperature changes further aggravated the problem. We intend to pursue our studies using a red color index like $V-R$ and observe another field star with a hotter effective temperature.

V. SUMMARY

We have discussed some reasons for attempting to measure distances to globular clusters without the use of field star calibrators. The Baade-Wesselink method can now be applied to cluster variables directly, and we have begun such a program by first studying some field stars to test our techniques and the method itself, as well as to look for signs of variations in $\langle M_v \rangle_{RR}$ in the field stars. We have obtained simultaneous high-accuracy photometric and radial velocity data for the field star VY Serpentis, which is only lightly reddened and does not show a variable pulsation amplitude, but which is rather cool. Use of two variations of the Baade-Wesselink method that both allow for the star's measured low metallicity, and its variable gravity resulted in an observed phase shift, $\Delta\phi \sim 0.075$, between the photometric and spectroscopic radii, with the latter leading the former. We have discussed possible causes of such a shift, and concluded that the methodology is viable, but that VY Ser is probably afflicted by a systematic distortion of its color due to penetration of convection into the continuum-forming layers. Observations of a hotter variable with redder color indices should yield superior results and will be undertaken soon.

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BRUCE W. CARNEY: Department of Physics and Astronomy, Phillips Hall 039A, University of North Carolina, Chapel Hill, NC 27514

DAVID W. LATHAM: Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138