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Hα AS A TEMPERATURE INDICATOR IN CEPHEIDS

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ABSTRACT

The gross behavior of the Hα profile is examined for a number of Cepheids, and it is found that large distortions occur only for stars with $\langle (B - V)^0 \rangle$ redder than about 0.80. A comparison is made between the wings of the measured profiles of four Cepheids and a series of newly computed profiles in order to determine whether the temperature variations can be studied in this way. For two of the stars, η Aql and S Nor, it is found that the profiles do not agree well and the resulting temperature curves differ in shape from the color curves during the later part of descending light and during ascending light. For the other two stars, U Sgr and Y Oph, the profiles agree during the entire cycle and the temperature curves determined agree in shape with the color curves.

I. INTRODUCTION

It has been shown (Rodgers and Bell 1967) that the Hα line is useful in Cepheids as a temperature indicator because, occurring in the red part of the spectrum, it is not seriously distorted by other absorption lines, and also because it is sensitive to temperature but relatively insensitive to gravity. However, the profile is badly distorted in a number of long-period Cepheids (Sanford 1956; Kraft 1957; Bell and Rodgers 1967; Rodgers and Bell 1968) and cannot be used to determine the temperatures. In the present paper the profiles are examined for stars in various locations in the instability strip to find when serious distortions occur. The wings of profiles which do not show serious distortions are then compared with calculated line profiles to determine whether they can be used as temperature indicators.

II. OBSERVATIONS

A number of high- and intermediate-dispersion spectra in the Hα region of the spectrum were used in this investigation. The high-dispersion spectra were obtained with the 32-inch camera of the coudé spectrograph of the Mount Stromlo 74-inch telescope and have a dispersion of 10.2 Å mm^{-1}. Baked IIa-O plates were generally used with an image tube, although a few 103a-F plates of the brighter Cepheids were taken without the image tube. The intermediate-dispersion spectra were obtained with the 10-inch camera of the coudé spectrograph at a dispersion of 33 Å mm^{-1}. The emulsions used in this case were 103a-F or IIa-E. These latter plates were all obtained by Dr. A. W. Rodgers, who kindly made them available to the author. The spectra may be distinguished by their plate numbers. The high-dispersion spectra have plate numbers greater than Cd 2500 while the intermediate-dispersion plates have smaller numbers.

The continuum was drawn on the spectral tracings in the usual fashion. In the case of the image-tube plates, the sensitivity variation of the tube gives rise to variations of the continuum which are of the order of 10 percent over a range of about 25 Å. To minimize errors from this source, one plate was chosen as a standard and the continuum carefully located on it. The continuum on all of the other image-tube plates was then determined by reference to the standard plate. That this procedure has pro-

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duced consistent continuum placement will become evident from the agreement of the temperatures determined from different plates.

In addition to the profiles, the displacement of the core of Hα relative to the metal lines was measured for four of the stars on some of the 32-inch camera plates. Between six and eleven neighboring lines were used to define the wavelength scale. The position of the center of the core was not ambiguous in any of these four stars since the cores were always reasonably symmetric.

III. THE COMPUTED Hα LINE PROFILES

For comparison with the observed Hα profiles, theoretical profiles were calculated from a series of model atmospheres. The model atmospheres are constant in radiative flux, and they range in temperature from $\theta_{\text{eff}} = 0.75$ to $\theta_{\text{eff}} = 0.95$ and in gravity from $\log g = 1$ to $\log g = 2$. The standard abundance adopted by Bode (1965) was used, and the opacities are consistent with his tables. These models have been fully described elsewhere (Schmidt 1969). The model calculations assume local thermodynamic equilibrium and hydrostatic equilibrium, are plane-parallel, and neglect convection. Although it is not to be expected that these assumptions are valid for Cepheids, it is probable that in at least some cases the wings of Hα will be affected only to a small degree. When these simple assumptions cause large errors in the wings, the line will not be useful as a temperature indicator since its profile will also depend on other factors (as is obvious from §IV). Since the purpose of this paper is to compare observed line wings with those calculated in order to determine the stars for which they can be used as temperature indicators, it is felt that more sophisticated models are unwarranted.

Two series of Hα lines were calculated. One series employed the Griem (1964) broadening theory; the other employed the Edmonds, Schlüter, and Wells (1967) broadening theory. In the calculation of the line opacities natural broadening, Doppler broadening, and self-broadening were included as well as Stark broadening.

Experiments with various models and parameters showed that the profiles are insensitive to the temperature distribution and the turbulent-velocity parameter but depend on both the gravity and the choice of broadening theory. The gravity must be known to obtain accurate temperatures from Hα since a change of a factor of 10 in the gravity can lead to changes in the derived temperature as large as 0.026 in θ_{eff}. From the shape of the profiles it is not possible to choose between the two broadening theories. However, several points tend to favor the Edmonds, Schlüter, and Wells theory: Strom and Peterson (1968), Olson (1968), and Newell (1969) all find that the gravities of early-type stars obtained from the hydrogen lines are in better agreement with those from other sources when the ESW theory is used than when the Griem theory is used; the ESW profiles indicate a temperature scale for Cepheids which is in agreement with that of Johnson (1966) (Schmidt 1969); the use of ESW profiles results in a temperature scale which agrees with that determined from continuum photometry provided the calibration of Hayes (1967) is used (Schmidt 1969). Since this is the case, the ESW profiles will be preferred here even though they give rise to a temperature scale which is hotter by 0.03 in θ_{eff} than that previously used which was based on Oke's (1961*a*, *b*) photometry of η Aql and δ Cep. The use of the Hayes calibration will bring Oke's results to the present temperature scale.

The profiles computed with the ESW theory are tabulated in Table 1. Also given are the full widths of the line at residual intensities of 0.9, 0.85, and 0.8 of the continuum intensity. The profiles for the Griem theory will be provided upon request. Gravity corrections which should be applied to the temperatures obtained by fitting the observed profiles to those calculated with $\log g = 1$ are given in Table 2.

IV. THE GROSS BEHAVIOR OF THE Hα LINE

Several authors have described the behavior of Hα in various Cepheids (Sanford 1956; Kraft 1957; Bell and Rodgers 1967; Rodgers and Bell 1968), but none has con-

TABLE 1

Hα PROFILES COMPUTED FROM THE EDMONDS, SCHLÜTER, AND WELLS BROADENING THEORY

	MODEL*																		
Δλ (Å)	FC2	FC12	FC14	FC8	FC5	FC17	FC19	FC9	FC1	FC6	FC7	FC10	FC4	FC16	FC18	FC11	FC3	FC13	FC15
0.5	...	...	...	...	...	...	...	...	...	...	...	...	...	.563	.581	.546	.564	.595	.635
1.0	...	...	...	...	...	...	...	...	.721	.743	.760	.754	.787	.807	.823	.820	.849	.866	.876
1.5	...	...	...	...	.730	.750	.762	.762	.792	.811	.826	.832	.852	.866	.876	.877	.900	.910	.916
2.0	.721	.735	.749	.750	.781	.797	.811	.810	.839	.856	.864	.865	.890	.900	.906	.910	.928	.935	.939
2.5	.761	.773	.784	.789	.818	.832	.842	.845	.870	.883	.893	.894	.914	.923	.927	.931	.945	.951	.954
3.0	.793	.803	.816	.820	.846	.859	.866	.871	.894	.903	.910	.914	.931	.938	.942	.945	.957	.961	.964
3.5	.820	.828	.835	.844	.869	.879	.888	.891	.911	.920	.924	.928	.943	.948	.952	.956	.965	.969	.970
4.0	.841	.850	.854	.864	.887	.895	.901	.907	.924	.932	.935	.939	.953	.957	.959	.963	.972	.974	...
4.5	.860	.865	.870	.881	.901	.908	.913	.919	.934	.941	.944	.948	.960	.963	.965	.969	...	...	...
5.0	.876	.880	.885	.895	.913	.920	.923	.929	.943	.948	.952	.956	.965	.969	.970	.973	...	...	...
5.5	.889	.892	.896	.906	.923	.928	.931	.937	.950	.955	.957	.961	.970	.973	...	...	...	...	...
6.0	.900	.902	.905	.916	.931	.935	.938	.944	.956	.960	.962	.966	...	...	...	...	...	...	...
6.5	.910	.912	.913	.925	.938	.942	.944	.951	.961	.964	.966	.970	...	...	...	...	...	...	...
7.0	.918	.920	.921	.932	.945	.947	.950	.956	.965	.968	.969	...	...	...	...	...	...	...	...
7.5	.926	.927	.927	.939	.950	.952	.954	.960	.968	.971	.972	...	...	...	...	...	...	...	...
8.0	.933	.933	.933	.944	.955	.956	.958	.964	.972	...	...	...	...	...	...	...	...	...	...
8.5	.938	.938	.938	.949	.959	.960	.961	.967	...	...	...	...	...	...	...	...	...	...	...
9.0	.944	.943	.943	.954	.962	.963	.964	.970	...	...	...	...	...	...	...	...	...	...	...
9.5	.948	.947	.947	.957	.966	.966	.967	...	...	...	...	...	...	...	...	...	...	...	...
10.0	.952	.951	.951	.961	.968	.969	.970	...	...	...	...	...	...	...	...	...	...	...	...
$w_{.90}$	12.0	11.7	11.5	10.6	8.8	8.5	7.9	7.6	6.1	5.8	5.3	5.2	4.3	4.0	3.8	3.7	3.2	2.7	2.6
$w_{.85}$	8.5	8.0	7.7	7.3	6.2	5.7	5.2	5.0	4.3	3.9	3.7	3.6	3.1	2.7	2.5	2.5	2.0	1.7	1.7
$w_{.80}$	6.3	5.9	5.5	5.4	4.5	4.1	3.7	3.8	3.2	2.7	2.6	2.6	2.1	1.9	1.7	1.7	1.5	1.3	1.3

* Model FC2: $\theta_{\rm eff} = 0.75$, $\log g = 1.0$.
Model FC12: $\theta_{\rm eff} = 0.75$, $\log g = 1.5$.
Model FC14: $\theta_{\rm eff} = 0.75$, $\log g = 2.0$.
Model FC8: $\theta_{\rm eff} = 0.775$, $\log g = 1.0$.
Model FC5: $\theta_{\rm eff} = 0.80$, $\log g = 1.0$.
Model FC17: $\theta_{\rm eff} = 0.80$, $\log g = 1.5$.
Model FC19: $\theta_{\rm eff} = 0.80$, $\log g = 2.0$.
Model FC9: $\theta_{\rm eff} = 0.825$, $\log g = 1.0$.
Model FC1: $\theta_{\rm eff} = 0.85$, $\log g = 1.0$.
Model FC6: $\theta_{\rm eff} = 0.85$, $\log g = 1.5$.
Model FC7: $\theta_{\rm eff} = 0.85$, $\log g = 2.0$.
Model FC10: $\theta_{\rm eff} = 0.875$, $\log g = 1.0$.
Model FC4: $\theta_{\rm eff} = 0.90$, $\log g = 1.0$.
Model FC16: $\theta_{\rm eff} = 0.90$, $\log g = 1.5$.
Model FC18: $\theta_{\rm eff} = 0.90$, $\log g = 2.0$.
Model FC11: $\theta_{\rm eff} = 0.925$, $\log g = 1.0$.
Model FC3: $\theta_{\rm eff} = 0.95$, $\log g = 1.0$.
Model FC13: $\theta_{\rm eff} = 0.95$, $\log g = 1.5$.
Model FC15: $\theta_{\rm eff} = 0.95$, $\log g = 2.0$.

sidered in detail the variation of this behavior with location in the instability strip. For this purpose, the spectra of fifteen Cepheids of different periods and colors were traced. The results of the examination of these tracings are given in Table 3. Also given are the results from the above authors. The phases listed for the individual plates were calculated with the ephemerides from the *General Catalog of Variable Stars* (Kukarkin *et al.* 1958) except for four of the stars (U Sgr, η Aql, S Nor, and Y Oph) for which elements of the variation were derived from published photometry (Schmidt 1969). The mean colors come from Fernie (1967); the color excesses are from Sandage and Tammann (1968) for the stars which they list (except for the four stars mentioned in the previous sentence for which the results of Schmidt [1969] were used) and from Fernie (1967) for the others.

Three criteria for describing the line shapes were used. The first criterion was symmetry, which is indicated in column (6) of the table. The second criterion was the presence of a discernible emission feature in the line wings. This was taken to include only profiles which clearly showed an intensity increase superimposed in the line. The third criterion was the splitting of the core of the line. When this occurs or is likely, it is indicated in column (8) of the table. The criteria are illustrated in Figure 1 in which some

TABLE 2

GRAVITY CORRECTIONS TO θ_{eff}
(ESW Profiles)

	θ_{eff}			
log g	0.75	0.80	0.85	0.90
1.0.....	0.000	0.000	0.000	0.000
1.5.....	−0.009	−0.010	−0.013	−0.012
2.0.....	−0.018	−0.020	−0.026	−0.024

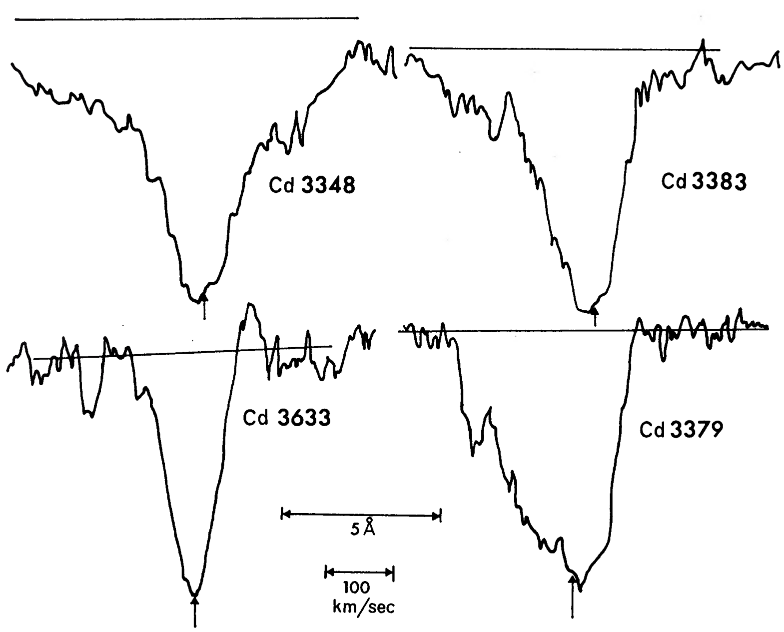

FIG. 1.—Examples of Hα profiles in several Cepheids. Cd 3348 shows a symmetric profile without apparent distortion. Cd 3633 has an emission component, while Cd 3383 and Cd 3379 illustrate asymmetric lines without and with splitting of the core.

of the line profiles are reproduced. The asymmetry of the line shown in Cd 3383 and the asymmetry and core splitting shown in Cd 3379 are never observed in nonvariable yellow supergiants and probably arise from the pulsational motions of the atmospheres. On the other hand, the occasional emission feature shown in Cd 3633 also occurs in nonvariable stars and is probably a chromospheric effect.

The information given in Table 3 was used to construct Figure 2. This is the color-magnitude diagram of the Cepheid strip in which the symbols indicate the form of the Hα profiles. The locations of the stars were found from the colors and periods given in Table 3 together with the Sandage and Tammann (1969) period-luminosity-color relation. The striking feature of this diagram is that for periods shorter than about 25 days the badly distorted Hα profiles which are observed for some Cepheids are confined to stars

TABLE 3

DESCRIPTION OF Hα PROFILES IN VARIOUS CEPHEIDS

Star (1)	Plate Number (2)	Phase (3)	Period (days) (4)	$\langle (B-V)_0 \rangle$ (5)	Symmetry (6)	Emission (7)	Core Splitting (8)
R TrA.....	2440	0.01	3.39	0.54	Yes	No	No
AH Vel....	3214	0.06	4.23	0.46	Yes	No	No
	3215	0.06			Yes	No	No
	3345	0.09			Yes	No	No
	2448	0.51			Yes	No	No
S Cru......	3348	0.04	4.69	0.61	Yes	No	No
TT Aql....	3587	0.07	13.75	0.84	No	No	Yes
	3688	0.10			No	No	Yes
	3694	0.10			No	No	Possibly
	3614	0.14			No	No	Yes
VY Car....	2436	0.84	18.93	0.89	No	No	Possibly
	2449	0.96			No	No	Yes
RY Sco....	3613	0.04	20.31	0.76	Yes	No	No
	3584	0.99			Yes	No	No
RZ Vel.....	3346	0.33	20.40	0.93	No	No	Yes
	3379	0.38			No	No	Yes
T Mon.....	2372	0.15	27.02	0.86	No	No	No
	3376	0.47			Yes	Yes	No
AQ Pup....	2397	0.66	29.86	0.88	No	No	Yes
	2373	0.79			No	No	Possibly
U Car.....	2400	0.12	38.76	0.96	No	No	Yes
	3353	0.41			No	No	Possibly
	3383	0.43			No	No	No
	3219	0.53			Possibly	No	No
	2438	0.89			Yes	No	No
RS Pup....	2441	0.79	41.38	0.87	Yes	No	No
U Sgr......	*	*	6.75	0.63	Yes	Briefly	No
η Aql......	*	*	7.18	0.69	Yes	No	No
S Nor......	*	*	9.75	0.78	Yes	No	No
Y Oph.....	*	*	17.12	0.60	Yes	No	No
β Dor......	†	†	9.84	0.61	Yes	No	No
S Mus.....	†	†	9.66	0.52	Yes	No	No
X Cyg.....	‡	‡	16.39	0.81	No	No	Yes
WZ Sgr....	‡	‡	21.84	0.81	No	No	Yes
1 Car......	§	§	35.56	1.06	No	Yes	Yes
SV Vul.....	#	#	45.10	0.92	No	No	No

* Plate numbers and phases listed in Table 6.
† Bell and Rodgers 1967.
‡ Kraft 1957.
§ Rodgers and Bell 1968.
# Sanford 1956.

in the red part of the strip. It can be seen that stars redder than about $\langle (B - V)^0 \rangle = 0.8$ are affected whereas those bluer are not. Unfortunately, no longer-period stars in the blue part of the strip were observed, so nothing can be said about the behavior at longer periods.

V. Hα VELOCITIES

The measured Hα core velocities relative to the metal lines are tabulated in Table 4. It is seen that U Sgr, Y Oph, and η Aql have small variations of the velocity, while S Nor exhibits a large variation. In S Nor the variation of the velocity is such that the layers in which the line core is formed lag in phase relative to the photosphere and have a larger velocity amplitude.

VI. COMPARISON BETWEEN OBSERVED AND CALCULATED PROFILES

The observed and computed profiles were fitted in the wings between residual intensities of about 0.75 and 0.95. Since the fit could not be improved significantly by

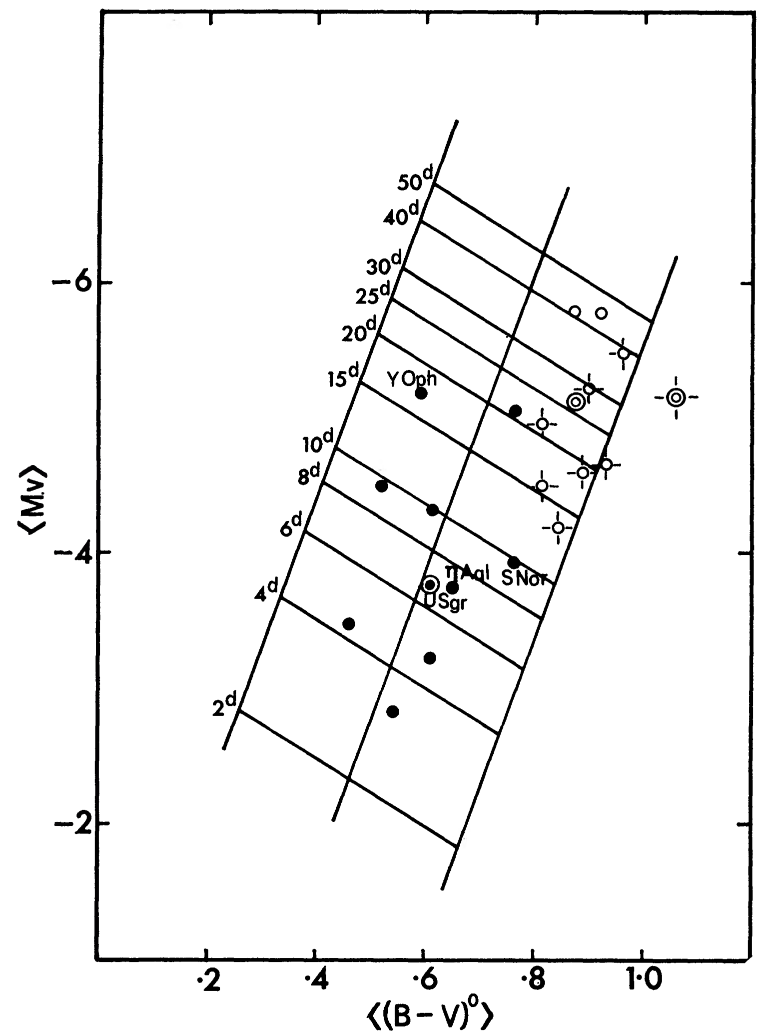

FIG. 2.—The location in the H-R diagram of Cepheids. Solid circles indicate that the Hα profile is always symmetric; open circles indicate asymmetry at some time during the cycle. Spikes and circle around the symbol denote core splitting and emission, respectively, during some part of the cycle The period lines and edges of the strip come from Sandage and Tammann (1969).

changing the gravity, all fittings were made to computed profiles with log $g = 1$. The resulting temperatures are listed in Table 5. For each profile the quality of the fit is indicated by letters B, C, D, or E. B and C indicate satisfactory fits, whereas D and E indicate poor fits. No difference in the quality of the fit was found between the Griem and the ESW broadening theories. While for Y Oph and U Sgr there are no phases for which the fits are uniformly poor, in η Aql the profiles fit poorly during the part of the cycle from 0.48 to 0.6 and for S Nor the quality of the fits is low from phase 0.3 to 0.9. The differences between the observed and computed profiles are of the same order of magnitude as the photometric errors, so only a general indication can be gained of when the profiles are disturbed.

Also listed in Table 5 are the gravities of the stars at the phases given. These were determined from a fine analysis of the iron spectrum which will be described elsewhere. These gravities and Table 2 were used to correct the temperatures. The corrected temperatures are listed in Table 5, and those for the ESW profiles are plotted in Figure 3. The solid curves in the diagram are mean lines drawn through the points.

VII. DISCUSSION

A comparison of the temperatures indicated by the Hα profiles with those indicated by the colors can be made using a color-temperature relation. As mentioned above, the

TABLE 4

RADIAL VELOCITIES OF THE CORE OF Hα RELATIVE TO METAL LINES

Plate Number	Phase	V_R (km sec⁻¹)	Plate Number	Phase	V_R (km sec⁻¹)	Plate Number	Phase	V_R (km sec⁻¹)	Plate Number	Phase	V_R (km sec⁻¹)
Y Oph			S Nor			U Sgr			η Aql		
3767....	0.00	+ 8	2710...	0.04	+ 6	3758...	0.04	− 7	2730...	0.09	−10
3680....	0.08	− 0.5	2820...	0.11	+10	2841...	0.10	− 3	3437...	0.20	− 9
3699....	0.19	− 1	2829...	0.21	+ 1	2850...	0.23	− 1	2783...	0.49	+ 5
2812....	0.29	+ 1	2662...	0.32	−11	2689...	0.35	− 0.5	3695...	0.60	− 5
3571....	0.40	− 3	2870...	0.46	−16	3612...	0.45	+ 1	3697...	0.74	− 1
2856....	0.52	− 0.5	3696...	0.52	− 6	2819...	0.68	+ 1	3633...	0.98	−15
3632....	0.57	+ 2	3581...	0.55	− 5	3700...	0.75	+ 1			
2717....	0.65	+ 9	3698...	0.61	+ 7	3747...	0.89	+13:			
3746....	0.82	+ 5	3601...	0.64	+ 4						
3757....	0.88	+ 5	3624...	0.74	+18						
			2811...	0.80	+19						
			3771...	0.88	+15						
			3778...	0.90	0						

zero point of the present scale is somewhat different from that found previously by Oke. However, with his slope, $\Delta\theta/\Delta(B - V) = 0.337$, and with a zero point consistent with the current temperature scale, it is possible to compare the variation of the Hα temperatures with the colors. The dashed lines in Figure 3 indicate the temperature variation derived in this way from $B - V$. It is seen that for Y Oph and U Sgr and during the early parts of the cycles of η Aql and S Nor the temperatures determined from the line profiles agree with those determined from the colors. The small differences are due to blanketing effects which will be discussed elsewhere. However, during the later parts of the cycles of S Nor and η Aql large discrepancies occur. This happens after phase 0.45 in η Aql and after phase 0.2 in S Nor. These are roughly the times during which it was noted above that the profiles did not fit well. A comparison of the observed with computed profiles indicates that when the profiles are fitted in the part of the line between residual intensities 0.8 and 0.9 the wings of the observed profiles above 0.9 are

TABLE 5

MEASURED Hα PROFILES AND DERIVED TEMPERATURES

Plate Number	Phase	Width (Å) 0.9	Width (Å) 0.85	Width (Å) 0.8	log g=1 Assumed θ_{eff} (Griem)	log g=1 Assumed θ_{eff} (ESW)	log g	Corrected Quality for Gravity of Variation Fit θ_{eff} (Griem)	Corrected Quality for Gravity of Variation Fit θ_{eff} (ESW)	Quality of Fit
					Y Ophiuchi					
3767.....	0.00	12.7	7.7	4.8	0.795	0.757	1.1	0.794	0.755	E
3768.....	0.00	13.4	8.7	5.6	0.768	0.746	1.1	0.767	0.744	C
3667.....	0.07	14.2	9.0	6.2	0.769	0.735	1.3	0.766	0.730	C
3679.....	0.08	11.9	8.9	6.2	0.778	0.754	1.4	0.774	0.747	C
3680.....	0.08	13.3	9.4	6.9	0.766	0.733	1.4	0.762	0.726	B
3699.....	0.19	10.1	7.0	5.1	0.808	0.780	2.0	0.795	0.761	C
3540.....	0.21	7.7	5.7	4.4	0.837	0.815	2.0	0.822	0.793	C
3551.....	0.22	9.0	6.8	5.5	0.814	0.787	2.0	0.801	0.767	D
2777.....	0.25	6.3	4.1	3.0	0.873	0.847	2.1	0.856	0.819	B
2443.....	0.28	6.7	4.8	3.5	0.866	0.839	2.2	0.846	0.809	D
2812.....	0.29	6.7	4.8	3.5	0.860	0.839	2.2	0.840	0.809	D
2817.....	0.29	7.6	5.6	4.1	0.850	0.817	2.2	0.831	0.789	D
3571.....	0.40	7.3	5.2	3.9	0.853	0.826	2.3	0.832	0.796	D
2827.....	0.41	6.4	3.9	2.9	0.874	0.848	2.3	0.853	0.815	C
2835.....	0.46	6.3	4.3	3.2	0.871	0.843	2.3	0.850	0.810	B
2840.....	0.46	6.4	4.3	3.0	0.872	0.851	2.3	0.851	0.815	B
2856.....	0.52	4.3	3.1	2.5	0.914	0.893	2.3	0.901	0.862	C
2861.....	0.53	6.0	4.3	3.1	0.887	0.862	2.3	0.868	0.829	D
2862.....	0.53	4.2	3.2	2.5	0.914	0.898	2.3	0.901	0.867	D
2675.....	0.54	6.7	4.4	3.1	0.870	0.853	2.3	0.849	0.816	C
3632.....	0.57	6.0	4.5	3.6	0.869	0.850	2.3	0.848	0.816	C
2890.....	0.58	5.2	3.3	2.8	0.891	0.874	2.3	0.873	0.842	C
2899.....	0.59	6.2	3.6	2.7	0.884	0.860	2.3	0.865	0.827	B
2717.....	0.65	5.9	3.9	2.9	0.890	0.870	2.2	0.874	0.840	C
2664.....	0.67	6.5	4.8	3.2	0.869	0.847	2.2	0.849	0.816	C
2665.....	0.67	6.2	4.1	3.1	0.879	0.857	2.2	0.860	0.826	D
2606.....	0.73	7.2	4.7	3.4	0.875	0.856	2.2	0.856	0.825	D
3733.....	0.76	8.8	4.7	3.1	0.846	0.820	2.1	0.829	0.796	D
3744.....	0.76	10.2	6.6	4.5	0.816	0.788	2.1	0.801	0.766	C
3745.....	0.77	13.4	6.6	4.7	0.803	0.780	2.1	0.789	0.759	C
2612.....	0.79	9.8	6.0	3.9	0.823	0.795	2.1	0.806	0.773	C
2613.....	0.79	8.9	6.0	4.4	0.827	0.806	2.1	0.811	0.784	C
3746.....	0.82	12.7	7.5	4.9	0.790	0.768	2.0	0.779	0.750	C
3751.....	0.88	10.5	6.9	4.8	0.808	0.785	1.8	0.798	0.769	D
3757.....	0.88	10.9	7.0	5.4	0.804	0.772	1.8	0.794	0.757	C
3759.....	0.94	11.0	7.3	5.4	0.802	0.770	1.5	0.796	0.761	B
2604.....	0.98	7.9	5.5	4.1	0.845	0.822	1.2	0.842	0.817	D
					U Sagittarii					
3389.....	0.00	7.7	5.9	4.7	0.830	0.809	1.4	0.824	0.801	D
2667.....	0.01	11.0	7.7	6.1	0.787	0.761	1.4	0.783	0.754	B
2668.....	0.01	10.9	6.8	5.4	0.800	0.772	1.4	0.795	0.764	C
3758.....	0.04	13.9	9.7	7.0	0.767	0.729	1.3	0.765	0.725	B
2841.....	0.10	8.2	5.9	4.6	0.834	0.808	1.4	0.828	0.800	B
2671.....	0.14	8.2	5.8	4.8	0.827	0.801	1.6	0.819	0.789	B
2672.....	0.14	9.4	6.2	4.8	0.823	0.795	1.6	0.815	0.783	B
2850.....	0.23	7.7	5.2	3.9	0.846	0.820	1.8	0.834	0.802	B
2855.....	0.24	6.6	4.8	3.5	0.871	0.849	1.8	0.858	0.829	C
2687.....	0.24	8.1	4.6	3.6	0.850	0.828	1.8	0.837	0.809	C
2863.....	0.26	7.2	4.6	3.4	0.853	0.833	1.8	0.840	0.814	C
2689.....	0.35	7.2	5.1	3.8	0.860	0.839	1.9	0.846	0.817	C
2880.....	0.38	5.8	3.8	3.2	0.882	0.856	2.0	0.868	0.830	C
2889.....	0.39	5.9	4.1	3.4	0.878	0.856	2.0	0.864	0.830	C
3606.....	0.42	4.6	3.5	2.9	0.889	0.874	2.0	0.876	0.849	E
3612.....	0.45	4.7	3.5	3.0	0.888	0.873	2.0	0.875	0.848	E
2723.....	0.52	4.0	3.3	2.9	0.909	0.898	2.1	0.897	0.871	D
2818.....	0.67	5.0	3.5	2.9	0.900	0.882	2.2	0.886	0.852	C

TABLE 5—*Continued*

Plate Number	Phase	Width (Å) 0.9	0.85	0.8	log $g=1$ Assumed θ_{eff} (Griem)	θ_{eff} (ESW)	log g	Corrected Quality for Gravity of Variation Fit θ_{eff} (Griem)	θ_{eff} (ESW)	Quality of Fit
					U Sagittarii					
2603.....	0.70	3.4	2.8	2.5	0.942:	0.919:	2.2	0.932:	0.891:	D
3700.....	0.75	6.6	3.8	2.9	0.875	0.853	2.3	0.854	0.820	C
3370.....	0.85	6.6	4.4	3.4	0.869	0.846	2.3	0.848	0.813	C
2272.....	0.86	3.5	2.9	2.5	0.929:	0.919:	2.3	0.919:	0.888:	C
3747.....	0.89	10.3	8.2	6.9	0.787	0.761	2.2	0.774	0.739	D
					η Aquilae					
2724.....	0.09	10.0	7.1	5.2	0.807	0.780	1.4	0.802	0.772	C
2730.....	0.09	11.2	7.9	5.5	0.795	0.773	1.4	0.790	0.765	B
3396.....	0.13	10.5	5.9	4.7	0.817	0.795	1.3	0.815	0.789	C
2778.....	0.48	4.6	3.3	2.6	0.904	0.887	1.7	0.896	0.870	D
2783.....	0.49	5.2	3.7	2.9	0.894	0.870	1.7	0.885	0.853	D
3569.....	0.56	5.4	4.2	3.4	0.880	0.863	2.3	0.860	0.830	D
3570.....	0.56	6.5	4.8	3.8	0.858	0.837	2.3	0.837	0.806	D
3695.....	0.60	6.5	3.8	3.0	0.876	0.853	2.6	0.849	0.811	C
3585.....	0.70	7.5	5.3	7.8	0.848	0.826	2.6	0.823	0.789	C
3586.....	0.70	7.6	5.4	4.1	0.845	0.823	2.6	0.820	0.787	C
3697.....	0.74	7.0	4.5	3.3	0.872	0.847	2.6	0.845	0.807	C
3615.....	0.84	6.5	4.9	3.9	0.864	0.840	2.0	0.849	0.815	C
3616.....	0.84	7.6	5.3	4.2	0.845	0.824	2.0	0.829	0.801	C
2702.....	0.96	8.4	6.6	5.6	0.817	0.788	1.0	0.817	0.788	D
3633.....	0.98	13.5	8.7	6.5	0.770	0.736	1.0	0.770	0.736	B
					S Normae					
2710.....	0.04	7.8	5.5	4.3	0.836	0.816	1.5	0.829	0.805	B
2716.....	0.04	10.0	7.2	5.8	0.799	0.777	1.5	0.793	0.768	C
2775.....	0.07	9.6	7.2	5.5	0.806	0.779	1.5	0.800	0.770	B
2776.....	0.09	7.1	5.2	4.0	0.853	0.833	1.5	0.845	0.821	C
2820.....	0.11	6.6	5.0	4.0	0.862	0.835	1.4	0.856	0.825	C
2441.....	0.12	11.1	6.8	5.1	0.801	0.778	1.4	0.796	0.770	C
2829.....	0.21	6.6	4.3	3.5	0.873	0.847	1.4	0.867	0.836	D
2834.....	0.22	5.7	4.3	3.4	0.881	0.862	1.4	0.875	0.852	B
2445.....	0.22	8.8	6.7	5.3	0.821	0.793	1.4	0.815	0.785	C
2844.....	0.31	5.3	4.1	3.5	0.889	0.864	1.5	0.883	0.851	D
2662.....	0.32	6.6	5.0	4.0	0.868	0.835	1.5	0.861	0.823	D
2663.....	0.32	6.6	4.9	3.8	0.858	0.837	1.5	0.850	0.825	C
2849.....	0.32	6.0	4.3	3.3	0.877	0.856	1.5	0.870	0.843	D
2602.....	0.34	5.1	4.4	3.7	0.887	0.862	1.7	0.877	0.844	E
2870.....	0.41	5.5	3.9	3.3	0.890	0.870	2.6	0.866	0.830	C
2879.....	0.42	5.0	3.9	3.3	0.891	0.877	2.7	0.866	0.835	D
3696.....	0.52	5.0	4.0	3.2	0.887	0.867	3.8	0.845	0.796	D
3575.....	0.54	5.1	3.7	3.2	0.889	0.874	3.7	0.849	0.807	C
3581.....	0.55	6.3	4.4	3.2	0.877	0.855	3.7	0.839	0.786	D
3698.....	0.61	6.9	3.6	2.9	0.876	0.849	3.5	0.841	0.784	C
3601.....	0.64	7.4	4.8	3.2	0.864	0.849	3.3	0.834	0.789	E
2609.....	0.68	4.0	3.0	2.7	0.912:	0.897:	3.2	0.886	0.844:	E
2610.....	0.69	5.5	3.8	3.1	0.882	0.851	3.2	0.852	0.794	B
3624.....	0.74	7.2	5.1	4.1	0.859	0.832	2.8	0.832	0.790	C
3630.....	0.74	6.8	5.2	4.3	0.853	0.837	2.8	0.826	0.794	D
2615.....	0.79	7.8	6.2	5.1	0.837	0.810	2.6	0.813	0.776	D
2811.....	0.80	6.4	5.4	4.8	0.858	0.830	2.5	0.835	0.794	D
2681.....	0.86	8.4	6.1	5.0	0.825	0.797	2.1	0.810	0.775	B
3771.....	0.88	8.1	6.3	4.9	0.826	0.809	2.0	0.812	0.788	D
3778.....	0.90	9.0	7.0	5.9	0.806	0.783	1.9	0.795	0.766	D
2696.....	0.96	8.0	5.6	4.3	0.837	0.816	1.6	0.828	0.803	B
2701.....	0.97	8.1	5.9	4.6	0.834	0.812	1.6	0.825	0.799	C

narrower than the computed profiles. On the other hand, if a profile with the temperature indicated by the color is compared with the observed profiles, it is found that the observed profile is wider except possibly in the outermost part of the wings. This, then, implies that the distortion of the profiles is due to the overlying absorption of the core becoming so broad that it interferes with the wings. It is therefore concluded that the temperatures indicated by the Hα profile are correct so long as the chromospheric core of the line does not overlie the part of the line used in the analysis. When this occurs, it will be apparent because it will result in poor agreement in shape between the computed and the measured profiles and because it will cause the temperature curve to differ in shape from the color curve. The conclusion that the temperatures derived

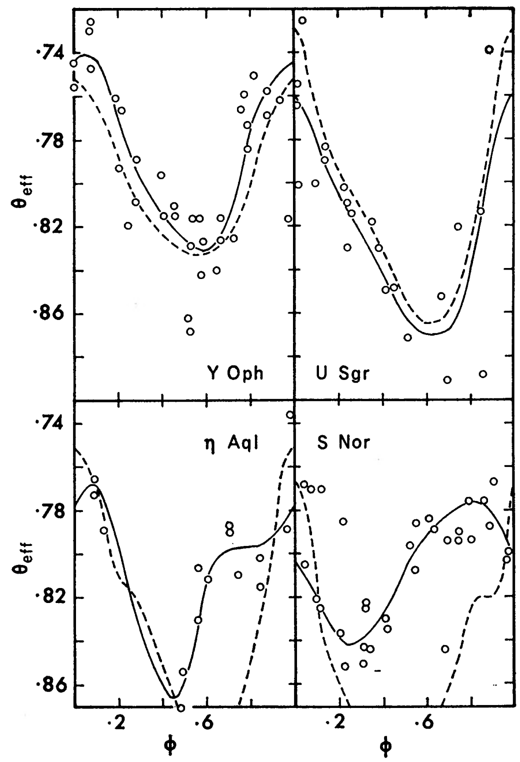

FIG. 3.—Temperature variations measured using Hα profiles from the Edmonds, Schlüter, and Wells broadening theory. *Dashed lines,* temperature obtained from $B - V$.

from Hα are accurate is supported by a comparison of these temperatures with those obtained from the continuum energy distributions (Schmidt 1969) which will be published separately.

The fact that Hα can be used as a temperature indicator in some Cepheids, in spite of the crudeness of the model atmospheres, provides an easy method for determining the temperatures of Cepheids which are at least as blue as U Sgr ($\langle (B - V)^0 \rangle = 0.63$). This in turn allows the determination of the intrinsic colors and color excesses of many individual Cepheids. Since it is quite obvious when the method fails, this should provide a safe and accurate method for such determinations.

Since Y Oph is the bluest known classical Cepheid in the Galaxy with a period greater than 12 days, it is of interest in connection with the pulsation theory. With this new temperature scale, the pulsational calculations of Stobie (1969) require a helium abundance greater than 60 percent in order for pulsation to occur. Even if we exclude Y Oph from the comparison with pulsational theory, the new temperature scale is enough hotter than the previous one that a helium abundance of about 55 percent is required to bring the calculated hot boundary of the strip into agreement with that determined by Stobie from Kraft's (1961) observational data. Such a high helium abundance is not expected for these stars, and it appears that the pulsation theory predicts a location for the hot boundary of the strip which is too cool by several hundred degrees.

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