THE ASTROPHYSICAL JOURNAL, 309:241–252, 1986 October 1

TEMPERATURES FOR HOT AND PULSATING DB WHITE DWARFS OBTAINED WITH THE *IUE* OBSERVATORY

JAMES LIEBERT[1]
Steward Observatory, University of Arizona
F. WESEMAEL[1]
Département de Physique and Observatoire du mont Megantic, Université de Montréal
C. J. HANSEN
Department of Astrophysical, Planetary, and Atmospheric Sciences and JILA, University of Colorado
G. FONTAINE
Département de Physique and Observatoire du mont Megantic, Université de Montréal
HARRY L. SHIPMAN[1]
Department of Physics, University of Delaware
EDWARD M. SION[1]
Department of Astronomy, Villanova University and Department of Physics, Arizona State University
D. E. WINGET
Department of Astronomy and McDonald Observatory, University of Texas at Austin
AND
RICHARD F. GREEN[1]
Kitt Peak National Observatory and Steward Observatory, University of Arizona
Received 1985 November 1; accepted 1986 March 21

ABSTRACT

Ultraviolet energy distributions are presented for 12 hot, helium-atmosphere DB white dwarfs, including the four known pulsating stars which define an empirical DB instability strip. Temperatures are derived exclusively from fits to the ultraviolet energy distributions, especially in the $\lambda\lambda$1200–2000 region which is most sensitive to temperature. Comparison is made between fits using atmospheric models from Wesemael and Wickramasinghe with those using a more detailed grid from Koester and with temperatures derived from optical observations. Uncertainties due to the model atmospheres, the *IUE* observations, and interstellar reddening are discussed.

The blue edge of the empirical DB instability strip is particularly uncertain, with a temperature using the *IUE* data in the range 29,000 ± 3000 K. This compares with 26,500 ± 2500 K if the optical temperature scale is adopted. The red edge lies near 24,000 ± 2000 K using *IUE* data but may lie 1000–2000 K cooler using optical data. We cannot establish whether any nonpulsating stars lie within the temperature range defined by the pulsators. The hottest DB star—and the only known one hotter than the instability strip—is PG 0112+104 near 30,000 K; this is the only known helium-atmosphere degenerate star which might lie in the interval 30,000 ≤ $T_{\rm eff}$ ≤ 45,000 K.

Subject headings: spectrophotometry — stars: white dwarfs — ultraviolet: spectra

I. INTRODUCTION

The DB white dwarfs are those with helium-rich atmospheres that are hot enough for neutral helium lines to be seen in their spectra, but not hot enough for He II lines to be seen. Some 98 DB stars are listed in the white dwarf catalog of McCook and Sion (1984). Several important investigations have produced estimates of temperatures and other parameters for most of these stars, but the estimates remain very uncertain for those with $T_{\rm eff}$ > 18,000 K. The determination of more accurate temperatures for the hotter DB stars is now important for two reasons: (1) Winget and collaborators (see later references) have recently found several pulsating stars among the hottest known DBs, and it is important to establish the existence and the boundaries of the presumed instability strip for this new kind of variable star. Calculations indicate that the boundaries of the theoretical instability strip are very sensitive to the assumed efficiency of mixing length convection used in the construction of the equilibrium models (Winget *et al.* 1983); (2) while the DB stars should range from about 11,000 K to about 40,000 K, above which the He II lines will appear (and they will be classified as DO stars), there is currently no DB star having $T_{\rm eff}$ > 30,000 K where the temperature has been determined reliably. At the same time, Wesemael, Green, and Liebert (1985) have analyzed 19 of the hotter DO stars, and the coolest of these has $T_{\rm eff}$ ≈ 45,000 K. This leaves a gap at 30,000 < $T_{\rm eff}$ < 45,000 K in which no helium-atmosphere degenerate star is currently known.

The *International Ultraviolet Explorer* (*IUE*) satellite observatory can play an important if not pivotal role in improving the temperature determinations for the hot DB stars. The problem with optical observations is twofold: (1) the energy distributions for these stars peak in the ultraviolet, so that optical fluxes must be measured on the Rayleigh-Jeans tail,

[1] Guest Observer at the *International Ultraviolet Explorer Observatory*, operated by NASA at Greenbelt.

requiring very accurate color values; (2) above about $T_{eff} \approx$ 18,000 K the neutral helium absorption lines reach a broad maximum in strengths and widths and become insensitive to temperature up to ~40,000 K. The *IUE* cameras, however, cover a wavelength interval ($\lambda\lambda$1200–3000) which includes, or is very near, the Planckian peak; thus improved temperatures may be estimated from spectrophotometry of only modest quality.

In the last few years we have attempted to identify and observe with *IUE* the hot DB stars in the Palomar Green Survey (Green, Schmidt, and Liebert 1986), as indicated from optical data. These include all four known pulsating DB stars. The ultraviolet spectrophotometry for several newly discovered DB stars is presented in § II; the energy distributions are matched with two separate grids of DB model atmosphere calculations, so that effective temperature estimates may be derived. In § III, the sources of uncertainty in the ultraviolet temperature fits are assessed, and a comparison with estimates from optical data is made. The conclusions attainable from this analysis are discussed in § IV.

II. *IUE* ENERGY DISTRIBUTIONS AND EFFECTIVE TEMPERATURES

a) The Observations

In Table 1 the *IUE* observing log for the 12 newly observed PG objects is presented. The first target was observed in 1982 using both the SWP camera covering $\lambda\lambda$1200–2000 Å and the LWR camera covering $\lambda\lambda$2000–3000 Å. The latter was not available for general use by early 1984. The remaining stars were observed with the SWP camera, and all but two were targeted for at least short exposures with the substitute LWP camera, a generally less-sensitive detector covering the $\lambda\lambda$2000–3000 Å range. In general the exposure times did not provide fully exposed spectra, but the fluxes were then binned in broad wavelength intervals for determination of the energy distribution. Reseau marks and recognizable ion events were eliminated. The standard *IUE* extraction and flux calibrations were used (Bohlin and Holm 1980; Cassatella and Harris 1983), together with the correction suggested by Hackney, Hackney, and Kondo (1982); in § III we discuss the effect of adopting the time-dependent revisions to the flux calibration developed by Sonneborn (1984) and Finley, Basri, and Bowyer (1984). Binned fluxes for the new PG stars are presented in Tables 2 and 3 and Figure 1. The energy distributions are

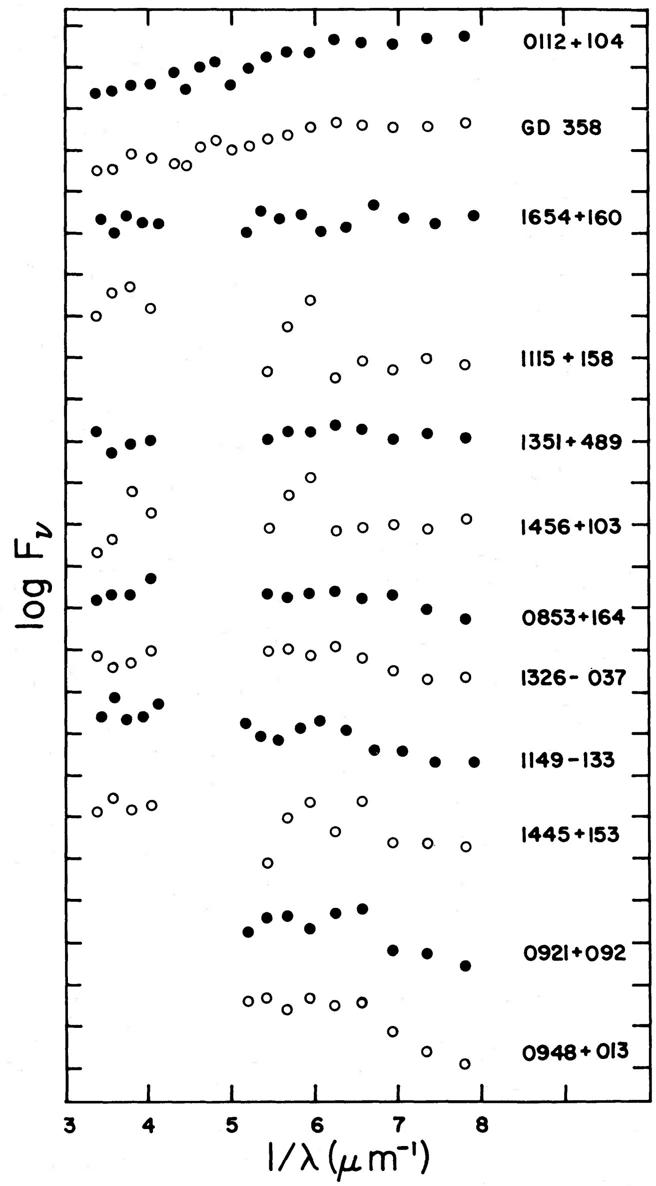

FIG. 1.—Binned ultraviolet energy distributions for the 12 program objects listed in Table 1. Logf_ν is plotted against $1/\lambda$ as in Tables 2 and 3. For GD 358, we show the observations of Vauclair (see Koester, Weidemann, and Vauclair 1983) rather than our more recent images listed in Table 1 (both sets of images are discussed in the text, and compared in Fig. 5). For PG 0112+104, we show the average of SWP 17403 and 17404 only. For two objects (PG 0921+091 and PG 0948+013), only the SWP images have been obtained. For most of the other stars, the noisy, short-wavelength end of the LWP camera has been omitted. Each tick mark on the vertical axis represents 0.125 dex in logf_ν, and the energy distributions have been arbitrarily shifted vertically. The order of presentation is approximately that for decreasing temperature (top to bottom). The apparent jumps near $1/\lambda \sim 6$ for PG 1115+158 and 1456+103 may be spurious and due to difficulties in extracting the low net signals for these objects.

TABLE 1

JOURNAL OF NEW *IUE* OBSERVATIONS OF HOT DB STARS

Target	Exposure	Date	Duration
PG 0112+104	SWP 17403	1982 Jul 11	60 min
	LWR 13655	1982 Jul 11	40 min
	SWP 17404	1982 Jul 11	35 min
PG 1654+160	SWP 22339	1984 Feb 23	66 min
	SWP 22355	1984 Feb 25	150 min
	LWP 2846	1984 Feb 25	60 min
PG 1149−133	SWP 22358	1984 Feb 25	120 min
	LWP 2848	1984 Feb 25	70 min
PG 0853+163	SWP 23030	1984 May 16	120 min
	LWP 3375	1984 May 16	60 min
PG 1115+158	SWP 23033	1984 May 17	120 min
	LWP 3376	1984 May 17	60 min
PG 1351+489	SWP 25299	1985 Feb 22	240 min
	LWP 5408	1985 Feb 22	120 min
PG 1326−037	SWP 25300	1985 Feb 22	120 min
	LWP 5409	1985 Feb 22	60 min
	SWP 25301	1985 Feb 22	100 min
GD 358	SWP 25310	1985 Feb 24	34 min
	LWP 5415	1985 Feb 24	34 min
PG 1445+152	SWP 25301	1984 Feb 22	100 min
	LWP 5410	1984 Feb 22	55 min
PG 1456+103	SWP 25311	1984 Feb 24	130 min
	LWP 5416	1984 Feb 24	45 min
PG 0921+091	SWP 25888	1985 May 08	50 min
PG 0948+013	SWP 25886	1985 May 08	120 min

1986ApJ...309..241L

TABLE 2

IUE ENERGY DISTRIBUTIONS FOR SEVERAL NEWLY OBSERVED DB STARS[a]

$1/\lambda$ (μm^{-1})	λ (Å)	PG 0112+104	GD 358	PG 1326−037	PG 0853+163	PG 1456+103	PG 1351+489	PG 1445+152	PG 1115+158	PG 0921+091	PG 0948+013
7.813...	1280	−25.153	−24.569	−25.583	−25.629	−25.753	−25.834	−25.771	−26.066	−26.035	−25.897
7.353...	1360	−25.164	−24.580	−25.588	−25.601	−25.785	−25.821	−25.764	−26.045	−25.995	−25.859
6.944...	1440	−25.178	−24.576	−25.563	−25.558	−25.770	−25.838	−25.759	−26.081	−25.987	−25.799
6.579...	1520	−25.173	−24.564	−25.523	−25.568	−25.778	−25.809	−25.633	−26.056	−25.862	−25.713
6.250...	1600	−25.166	−24.557	−25.492	−25.547	−25.789	−25.796	−25.724	−26.105	−25.874	−25.721
5.952...	1680	−25.204	−24.555	−25.519	−25.553	−25.631	−25.813	−25.636	−25.873	−25.921	−25.701
5.682...	1760	−25.203	−24.601	−25.503	−25.565	−25.682	−25.812	−25.685	−25.949	−25.886	−25.735
5.435...	1840	−25.218	−24.612	−25.507	−25.555	−25.781	−25.839	−25.819	−26.086	−25.888	−25.699
5.208...	1920	−25.254	−24.629:	−25.444	−25.502	−25.598	−25.780	−25.549	−25.701:	−25.931	−25.707
5.000...	2000	−25.302	−24.622:	−25.480	−25.498	−25.408	−25.809	−25.569	−25.703:		
4.808...	2080	−25.234	−24.576:	−25.399	−25.343	−25.369	−25.699	−25.475	−25.538:		
4.630...	2160	−25.251	−24.590:	−25.477	−25.381	−25.472	−25.732	−25.539	−25.651:		
4.464...	2240	−25.317	−24.602:	−25.357	−25.370	−25.435	−25.694	−25.448	−25.527:		
4.310...	2320	−25.269	−24.617:	−25.420	−25.453	−25.519	−25.892	−25.516	−25.669:		
4.167...	2400	−25.311	−24.615:	−25.489	−25.553	−25.629	−25.843	−25.623	−25.739:		
4.032...	2480	−25.298	−24.613	−25.510	−25.507	−25.735	−25.838	−25.643	−25.895		
3.906...	2560	−25.285	−24.604	−25.483	−25.551	−25.798	−25.853	−25.652	−25.951		
3.788...	2640	−25.305	−24.627	−25.546	−25.556	−25.673	−25.848	−25.659	−25.830		
3.676...	2720	−25.315	−24.628	−25.515	−25.534	−25.852	−25.824	−25.633	−25.948		
3.571...	2800	−25.322	−24.640	−25.559	−25.553	−25.811	−25.875	−25.622	−25.849		
3.472...	2880	−25.325	−24.623	−25.526	−25.510	−25.810	−25.802	−25.605	−25.922		
3.378...	2960	−25.328	−24.650	−25.524	−25.575	−25.853	−25.813	−25.664	−25.923		
3.289...	3040	−25.367	−24.651	−25.538	−25.658	−25.632	−25.866	−25.587	−25.835		

[a] $\log f_\nu$ (ergs cm^{-2} s^{-1} Hz^{-1}).

TABLE 3

IUE ENERGY DISTRIBUTIONS FOR TWO NEWLY OBSERVED DB STARS

		$\log f_\nu$ (ergs cm^{-2} s^{-1} Hz^{-1})	
$1/\lambda$	λ	PG 1654+160	PG 1149−133
7.905......	1265	-25.79 ± 0.03	-25.83 ± 0.05
7.463......	1340	-25.82 ± 0.03	-25.83 ± 0.05
7.067......	1415	-25.80 ± 0.03	-25.80 ± 0.05
6.711......	1490	-25.76 ± 0.03	-25.80 ± 0.05
6.390......	1565	-25.83 ± 0.04	-25.74 ± 0.05
6.098......	1640	-25.84 ± 0.04	-25.71 ± 0.07
5.831......	1715	-25.79 ± 0.04	-25.73 ± 0.07
5.587......	1790	-25.81 ± 0.04	-25.77 ± 0.07
5.362......	1865	-25.78 ± 0.04	-25.76 ± 0.07
5.189......	1927	-25.85 ± 0.04	-25.72 ± 0.07
4.843......	2065	-25.85 ± 0.06	-25.56 ± 0.08
4.577......	2185	-25.67 ± 0.06	-25.65 ± 0.08
4.338......	2305	-25.84 ± 0.06	-25.57 ± 0.08
4.124......	2425	-25.82 ± 0.04	-25.66 ± 0.05
3.929......	2545	-25.82 ± 0.03	-25.70 ± 0.05
3.752......	2665	-25.80 ± 0.03	-25.71 ± 0.05
3.591......	2785	-25.85 ± 0.03	-25.64 ± 0.05
3.442......	2905	-25.81 ± 0.03	-25.70 ± 0.05

plotted from top to bottom in approximate order of decreasing temperature, as determined in the next section.

b) *The Model Fitting*

Blanketed model atmosphere grids useful for comparison with these observations are available from Wesemael (1981 and unpublished), Koester (1980, 1981), and Wickramasinghe (1983). We are grateful to Detlev Koester for providing us with ultraviolet energy distributions for his detailed grid covering $12{,}000 \le T_{\rm eff} \le 30{,}000$ K in 2000 K steps. The Koester (1980) models assume trace abundances of hydrogen ($n_{\rm H} = 10^{-5} n_{\rm He}$) and metals ($n_M = 1.5 \times 10^{-5} n_{\rm He}$); the Koester (1981) models assume $n_{\rm H} = 10^{-6} n_{\rm He}$ and no metals. The Wesemael grid is coarser, but includes $T_{\rm eff} = 25{,}000$ K, 30,000 K, 35,000 K, and 40,000 K models. Zero helium and metals are assumed. The Wickramasinghe models cover the lower temperatures up to $T_{\rm eff} = 19{,}000$ K, and with a trace abundance of $n_{\rm H} = 10^{-5}\ n_{\rm He}$. In view of the good agreement between colors predicted by *unblanketed* DB model atmospheres of Wickramasinghe and Wesemael (see Wesemael 1981), it was therefore logical to combine the Wesemael and Wickramasinghe sets (the W grid) for comparison with the observations and the predictions of the Koester models (the K grid). The decision to combine the Wesemael and Wickramasinghe models into one grid is justified by arguments given in § III*a*. Two sets of *IUE* effective temperatures were derived for each observed star, one from the W and one from the K grid. The effective temperatures determined for our 12 newly observed objects and for a few additional hot DB stars are listed in Table 4, as are temperatures taken from the literature, usually based on optical data.

We have chosen to give higher weight in the fitting to the short wavelength (SWP) region of the spectrum than the long wavelength (LWR/LWP) region and to normalize the plots to $\lambda1850$ near the long end of the SWP camera. There were several reasons favoring this approach: (1) for stars at $T_{\rm eff} >$ 18,000 K, the SWP region is much more sensitive to temperature, and is on the Wien tail past the energy distribution peak for $T_{\rm eff} \le 24{,}000$ K; (2) the signal-to-noise ratios of the data for the LWR camera are generally inferior to those for the SWP, and the later LWP data are often very poor; and (3) the W and K models appear to offer good fits over the $\lambda\lambda1200$–2000 region (albeit sometimes for different values of $T_{\rm eff}$); it is often not possible to find a self-consistent fit with the models for both the shorter and longer wavelength intervals of the LWP/LWR data; (4) the time-dependent changes in camera sensitivity discussed in § III*b* proved to be larger for the LWR camera than for the SWP; (5) finally, we note that fluxed *IUE* data sometimes show an offset between exposures taken with the short and long wavelength cameras (see § III*b*), making it preferable to rely on data from the SWP camera alone. The flux offset near $\lambda2000$ might be caused by difficulties in calibrating very low net signals or by light losses due to variations in position of the star within the aperture.

In Figure 2 we illustrate the fitting of two of the hottest stars in our sample. GD 358 (PG 1645+325) is the first discovered pulsating DB star (Winget *et al.* 1982), while PG 0112+104 was found to be hotter than GD 358 based on optical spectrophotometry (Oke, Weidemann, and Koester 1984, hereafter OWK). Fast photometric observations of PG 0112+104 show, however, only an upper limit of <0.003 magnitudes for optical pulsations in the 10–1200 s period range (Robinson and Winget 1983). The archival data of Koester, Weidemann, and Vauclair (1983) are used to construct the GD 358 energy distribution for Figures 1 and 2. New SWP and LWP observations for this star are discussed in § III (but make a difference of only ~ 1000 K to the fitted temperature). Wesemael models for $T_{\rm eff} = 35{,}000$, 30,000, and 25,000 K are displayed with the data in Figure 2*a*, each normalized to the observed fluxes for the average of several binned points near $\lambda1850$ ($1/\lambda = 5.3\ \mu$m^{-1}) as discussed. In Figure 2*b*, the same data are compared with model energy distributions from the K grid.

Consistent fits for the SWP fluxes for both stars and both model sets are possible at temperatures of 29,000–30,000 K for PG 0112+104 and 27,000–28,000 K for the pulsating star GD 358. In each case, the lower temperature is assigned from the K grid (Table 4), while the W fit (Wesemael models only) is 1000 K higher. Note, however, that the fluxes for both stars are somewhat flatter than the models over the LWR interval. Had we normalized at $\sim\lambda2900$, the best temperature fits to the entire *IUE* interval would be similar, but the short wavelength end ($\lambda\lambda$ 2100–2600) of the LWR would show the data points falling below the models. This discrepancy is characteristic of our attempts to fit the observations of most of the stars. Accordingly, as discussed earlier, we chose in assigning best temperature fits for the stars in Table 4 to give higher weight to the SWP wavelengths; the lower bounds implied by the error bars listed in Table 4 generally reflect the temperatures derivable from giving greater weight to the $\lambda\lambda2000$–3000 region.

While there is good agreement between the K and W model fits to the *IUE* data for both hot stars, implying that they differ in $T_{\rm eff}$ by <2000 K, it is noteworthy that the temperature estimates using optical data (and the K grid) differ by a greater amount. OWK assign PG 0112+104 a temperature of 28,900 K, in nice agreement with the *IUE* fits and suggesting that this is the hottest known DB star. Yet the same authors (see Koester *et al.* 1985) favor an optically derived temperature of 24,000 K for GD 358. The latter seems to be in sharp disagreement with the SWP region fits for both W and K models.

If we assume that an instability strip exists for DB stars (Winget *et al.* 1982, 1983) analogous to the well-defined temperature region of the ZZ Ceti (DA) variable stars, then these two stars may bracket the high temperature boundary above 27,000–28,000 K using the *IUE* data. Alternatively, since GD 358 has the bluest energy distribution at *IUE* wavelengths of

TABLE 4

ASSIGNED TEMPERATURES FOR PG AND OTHER HOT DB WHITE DWARFS OBSERVED WITH *IUE*

WD Number, Name	T_W[a] ($\times 10^3$ K)	T_K[b]	T_{opt}[c]	Ref[d]	Variable?[e]
0112+104 PG	30 ± 1	29 ± 2	28.9 ± 0.56	OWK	S
1645+325 GD 358, PG	28 ± 1	27^{+1}_{-2}	24.6 ± 0.5 24 ± 1	OWK, KWV K85, Note f	V
1654+160 PG	26^{+2}_{-1}	25 ± 2		Note g	V
1115+158 PG	26 ± 2	25 ± 2		Note g	V
0308−566 BPM 17088	26 ± 1	23^{+1}_{-2}	>18 >18	WR KSW	?
1542+182 GD 190, PG	26 ± 1	23^{+2}_{-1}	22.67 ± 0.99	OWK	S
1351+489 PG	25 ± 2	24^{+1}_{-2}			V
0100−068 BPM 70524	25^{+1}_{-2}	$22 + 1$	19–23	OWK	?
1456+103 PG	24 ± 3	23^{+3}_{-1}			?
0853+163 LB 8827, PG	22^{+3}_{-2}	22^{+1}_{-2}			S
1326−037 PG	22 ± 3	21 ± 1			?
1149−133 PG	21^{+2}_{-3}	20 ± 2			?
0840+262 Ton 10, PG	21^{+2}_{-3}	21^{+1}_{-2}	17.31 ± 0.38	OWK Note h	S
2224−344 LDS785A	20 ± 2	20^{+1}_{-2}	19 ± 1	SW	?
1011+571 GD 303	19 ± 2	20 ± 2	17.18 ± 0.4	OWK	S
0418−539 BPM 17731	18^{+3}_{-2}	20^{+2}_{-3}	≥ 18	WR[i]	?
1445+152 PG	18^{+4}_{-2}	$19 + 2$			?
0921+091 PG	19^{+3}_{-1}	20 ± 2			S
0948+013 PG	18^{+4}_{-1}	18^{+3}_{-1}			?

[a] T_W temperatures assigned from *IUE* data giving highest weight to the shorter wavelengths (SWP) and using Wesemael models at T_e = 25,000, 30,000, and 35,000 K and Wickramasinghe models at 18,000 K and 19,000 K. Units are in 10^3 K; error bars usually given in second row.

[b] T_K temperatures assigned using energy distributions provided by Koester (1980, 1981) for models at T_e = 16,000 K, 18,000 K, 20,000 K, 22,000 K, 24,000 K, 26,000 K, 28,000 K, and 30,000 K, fitting to *IUE* data giving highest weight to the shorter wavelengths (SWP). Other notation as for T_K.

[c] T_{opt} temperatures as quoted from the literature, where optical data was generally used.

[d] References: OWK = Oke, Weidemann, and Koester 1984; WR = Wickramasinghe and Reid 1983; KSW = Koester, Schulz, and Wegner 1981; SW = Strittmatter and Wickramasinghe 1971; WW = Wickramasinghe and Whelan 1977; W83 = Wickramasinghe 1983; KWV = Koester, Weidemann, and Vauclair 1983, K85 = Koester *et al.* 1985.

[e] V: Variable (GD 358: Winget *et al.* 1982; PG 1654+160: Winget *et al.* 1984; PG 1115+158: Winget, Nather, and Kepler 1984; PG 1351+489: unpublished observations by Winget); S: Stable (Robinson and Winget 1983, and unpublished observations by Winget for PG 0853+163); ?: Not yet observed for variability.

[f] Note that KWV estimated $T_K \sim 28{,}000$ K from their *IUE* data alone.

[g] May not have been centered in SWP exposure.

[h] DBA star (with Hβ).

[i] Temperature consistent with 18,500 K from W83.

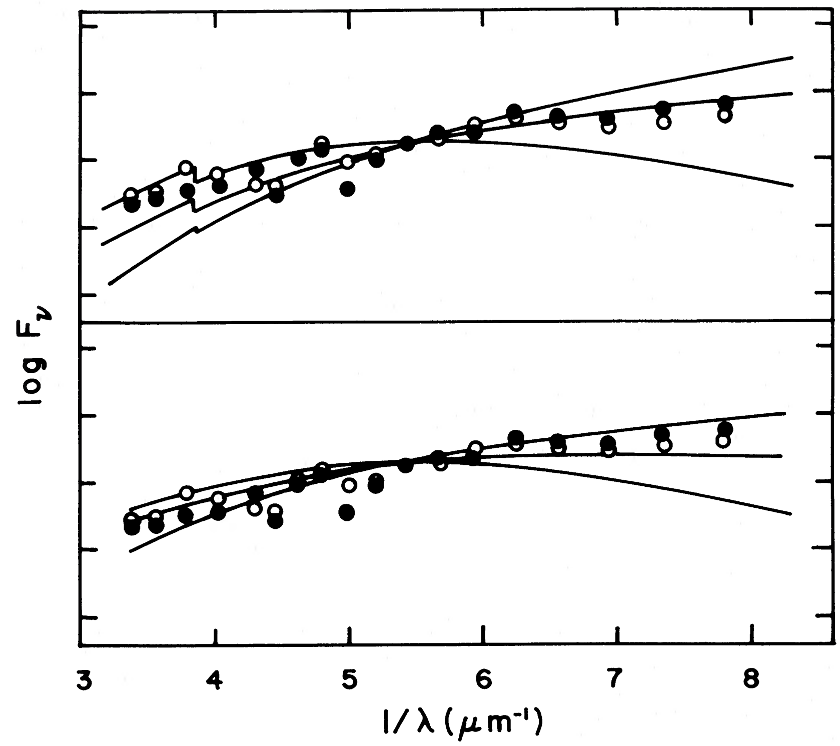

FIG. 2.—(*a*) Binned energy distributions of the hot DB stars PG 0112+104 (*filled circles*) and the Vauclair images of GD 358 (*open circles*), together with the fits based on the models of Wesemael (1981). The models shown here are for T_{eff} = 25,000, 30,000, and 35,000 K, and are normalized to the data at 1850 Å. (*b*) Same as (*a*), but with the fits based on the models of Koester (1980, 1983). The models displayed are at T_{eff} = 22,000, 25,000, and 30,000 K. The vertical scale is identical to that for Fig. 1 in this and Figs. 3–5. The "25,000 K model" curve used for Koester is actually the average of his 24,000 K and 26,000 K fluxes. Discrepancies especially between the Wesemael and Koester 25,000 K models are discussed in § III*a*.

the four known pulsating stars, the high temperature boundary could be as low as 24,000 K if we use the optically determined temperature. Note, however, that optical temperatures have not been determined for the other three pulsating stars.

In Figure 3, two somewhat cooler stars are plotted in the same way for comparison with the two grids. PG 1654+160, which pulsates (Winget *et al.* 1984), appears to fit about 25,000–26,000 K, although the noisy LWR points appear too high (indicating a cooler temperature) for both model sets. The nonpulsating PG 0853+163 may be assigned a fit near 22,000 K for both W and K curves, though the LWR data again set the lower bound in Table 4.

In Figure 4, we display fluxes for GD 190 (1542+182) pulled from the *IUE* archives and those for a cooler star GD 303 (1011+570). The former, which does not pulsate, has a T_{eff} fit virtually identical to that for the pulsating star PG 1654+160, for which the observations were quite noisy. GD 303 illustrates the fitting near the low end of the sample considered in this paper.

If there is a well-defined lower temperature limit to a pulsational instability strip, the results for GD 190, 1654+160, and 1115+158 suggest that it is near ~24,000–25,000 K, using *IUE* fluxes. The optically determined temperature (by OWK) for GD 190 is 22,670 K (Table 4), but the other two PG stars lack an optical determination.

III. UNCERTAINTIES IN THE *IUE* TEMPERATURES

It is apparent from comparison of the *IUE*-determined effective temperatures from both the W and K models with optically derived values in Table 4 that the methods do not agree, especially for temperatures near 25,000 K where the ultraviolet energy distributions predicted by the W and K models yield values of T_{eff} appreciably larger than the optical values. In Figure 6, we plot these *IUE* determined temperatures (both W and K) against optical temperatures taken from the literature, as listed in Table 4. It is apparent that the fitting of the ultraviolet energy distributions generally results in the assignment of higher temperatures between about 19,000 K (on an *IUE* scale) to about 28,000 K. The lone object (PG 0112+104) near 29,000–30,000 K offers good agreement on all three temperature scales used here. No known DB star has a temperature assigned from any scale above 30,000 K, as determined from blanketed models.

Previously, we have contrasted the great sensitivity of the ultraviolet energy distributions to temperature with the relative insensitivity of optical colors and line spectra for DB stars at or above 20,000 K. Nonetheless, a thorough discussion of the uncertainties in the *IUE* data as well as the physical uncertainties in the models is now warranted, given the striking discrepancies in the derived temperatures from the different methods (Table 4 and Fig. 6). Let us begin with the uncertainties in the models, for which a thorough investigation is now badly needed, but is beyond the scope of this paper.

a) Uncertainties with the Models

These divide into the categories of those having to do with uncertainties in the physical parameters (such as the hydrogen abundance) and those due to uncertainties in the physics (such as the treatment of convection). The first is easier to address: the hydrogen abundance is set to zero in the Wesemael models and has small trace values in the calculations of Koester and Wickramasinghe. Shipman's (1972) investigation of DB model

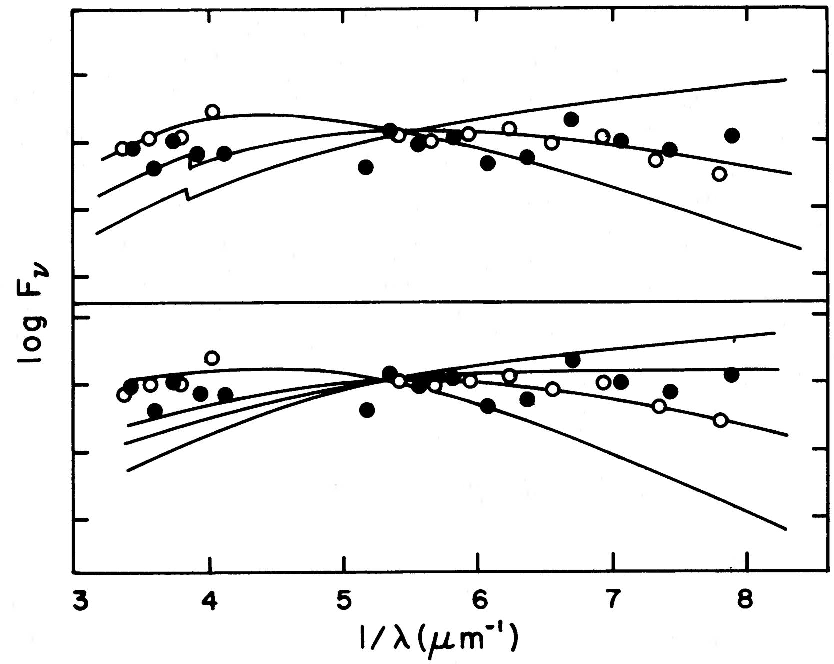

FIG. 3.—Binned energy distributions of the cooler DB stars PG 1654+160 (*filled circles*) and PG 0853+163 (*open circles*), together with the fits based on the models of Wesemael (1981). The models shown are for T_{eff} = 18,000, 25,000, and 30,000 K, and are normalized to the data at 1850 Å. (*b*) same as (*a*), but with the fits based on the models of Koester (1980, 1981). The models shown are for T_{eff} = 18,000, 22,000, 25,000, and 30,000 K.

atmospheres at temperatures below 20,000 K shows that the H opacity is small enough that it is probably safe to use pure He models to define the temperature structure (see also Shipman, Liebert, and Green 1986). At optical and ultraviolet wavelengths, hydrogen contributes only a few percent of the continuum opacity, so that effects on the sensitive ultraviolet colors should be minimal. Moreover, the effects of hydrogen should be even smaller at temperatures above 20,000 K where a greater fraction of helium is ionized. Previously we have noted the good agreement between unblanketed Wickramasinghe and Wesemael models (Wesemael 1981), which were calculated with differing hydrogen abundances. Similar arguments may be made regarding uncertainties due to undetectable abundances of heavier elements. Likewise, the assumption for the surface gravity is unlikely to be a significant effect on the temperature fitting (Shipman 1972); indications are that the surface gravities of DB stars may now be similar to those for DA stars anyway (Shipman, Greenstein, and Boksenberg 1977; OWK), in contrast to earlier claims. The use of helium line blanketed models has an important effect on the derived tem-

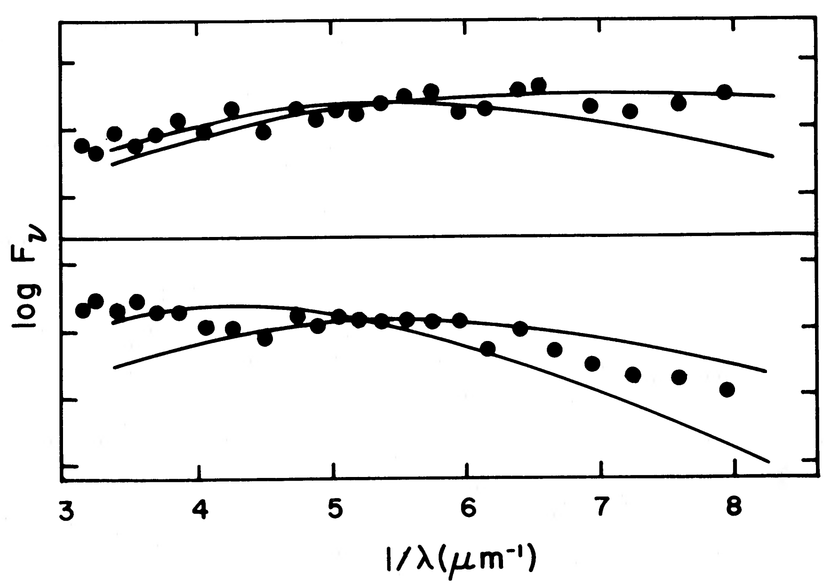

FIG. 4.—Binned energy distributions for the DB stars GD 190 (*top*) and GD 303 (*bottom*), obtained through the Astronomical Data Center. Fits achieved with Koester's (1980, 1981) models are also shown and are normalized to the data at 1850 Å. The models shown are for T_{eff} = 22,000 and 25,000 K (GD 190), and for T_{eff} = 18,000 and 20,000 K (GD 303).

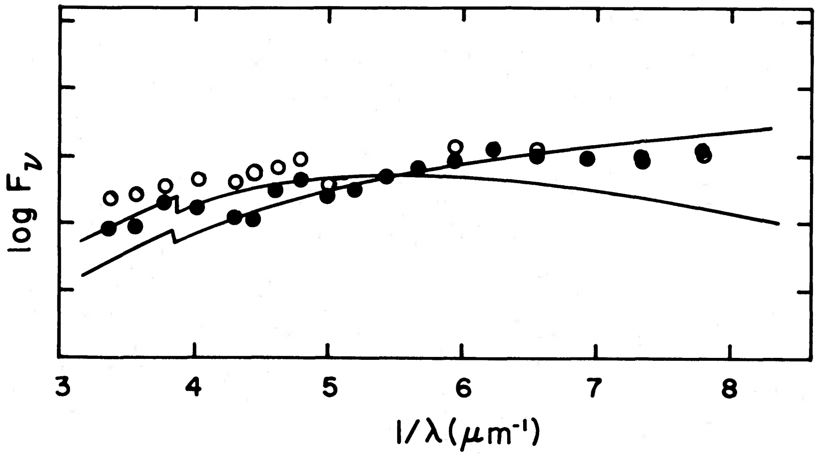

FIG. 5.—Binned energy distributions of GD 358 based on Vauclair's images (SWP 14015 and LWR 10668; *filled circles*), and our own recent reobservations (SWP 25310 and LWP 5415; *open circles*). The fits based on the models of Wesemael (1981) are also shown, with the models normalized to the data at 1850 Å. The models displayed are at T_{eff} = 25,000 and 30,000 K.

peratures; unblanketed models fitted to optical colors can imply temperatures several thousands of degrees cooler (e.g., as in Fontaine, Montmerle, and Michaud 1982). The K grid also includes blanketing due to the finite hydrogen abundance assumed.

It is interesting that the biggest discrepancies between the optical and *IUE*-derived temperatures and between the Wesemael and Koester models occur at ≤25,000 K, despite the good agreement at ~30,000 K. For standard convection theory, the onset of significant convective envelopes in helium atmosphere degenerates occurs at about 25,000 K and is of growing importance for cooler models. It is of course difficult to evaluate the effect of uncertainties in the simple mixing length theory of convection; indeed, one goal is to use the empirically determined temperature boundaries for the DB pulsational instability strip to calibrate the convective efficiency parameter (Fontaine, Tassoul, and Wesemael 1984). Below about 15,000 K the agreement in the temperature fits between optical and *IUE* data (Wickramasinghe 1983; Wickramasinghe and Reid 1983) is much better. Clearly, the temperature fits in the 19,000–28,000 K range are uncertain by at least 10%. On the other hand, it is likely that the temperature fit to the hot star PG 0112+104 near 29,000–30,000 K does not suffer from similar physical uncertainties in the modeling.

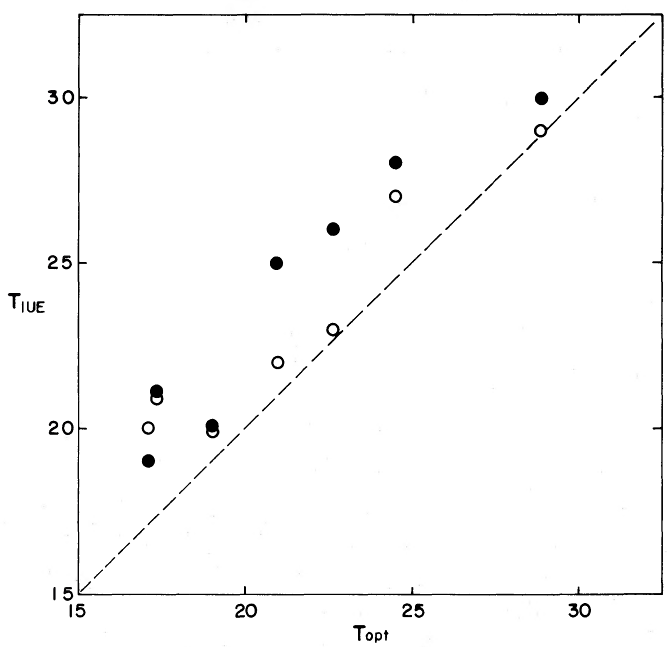

FIG. 6.—Plot of *IUE*-determined temperatures for hot DB stars, obtained from the Wesemael-Wickramasinghe models (*filled circles*) and the Koester grid (*open circles*), against optically determined values. All numbers are taken from Table 4. The diagonal (*dashed*) line is the locus of points with $T_{IUE} = T_{opt}$.

b) *Uncertainties in the IUE Flux Values*

Problems with calibrating *IUE* data include (1) possible offsets in the absolute flux values between observations taken with the short and long wavelength cameras, and with optical fluxes, and (2) time variability and other uncertainties in the relative flux calibrations.

Offsets in fluxes derived for the different *IUE* cameras may be caused by differences in the positioning of the target within the 10″ × 20″ large aperture between the SWP and LWR/LWP exposures. Usually, the optically faint stars were placed by blind offset from SAO catalog stars, and could not be detected for visual centering (the FES postage stamp); thus, an exact centering of targets could not generally be achieved. Experience with *IUE* observing shows that light losses are significant when the target is within 3″–4″ of the aperture end. Recorded flux may also be diminished if the *IUE* telescope drifts out of focus, due to changes in the spacecraft temperature which may occur rapidly at certain orientation (beta) angles with respect to the Sun. Our experience with mating optical multichannel spectrophotometer[2] (MCSP) fluxes and *IUE* fluxes for PG stars shows that an offset of <0.1 dex occurs some of the time (cf. Wesemael, Green, and Liebert 1985). Often the disagreement is attributable to modestly nonphotometric conditions for the optical observations and to difficulties in applying a mean extinction correction to the optical ultraviolet.

In order to avoid the offset problem and for other reasons outlined in § II, we prefer to match purely *IUE* energy distributions with the models. The normalization of the model fluxes and data to the long wavelength end of the SWP camera

[2] See OWK.

(λ1850) is also motivated largely by these considerations. A possible offset between the LWR and SWP data is apparent for the observations of PG 1115+158; the poor signal-to-noise ratio of the SWP scan of this star may be due to light losses and the general problem that the intensity transfer function (sensitivity) of the LWR camera is not well determined for faint flux levels.

The principal uncertainty in the relative *IUE* flux calibration is the time dependence of the camera sensitivities, as has been emphasized recently by Finley, Basri, and Bowyer (1984). The degradation of the cameras with time as a function of wavelength has been estimated using bright flux standards by the *IUE* support staff, the most recent determination being that of Sonneborn (1984). The time variability of the SWP camera is significantly less than that of the LWR, and it turns out that the effect on the relative *IUE* fluxes covering 1200–2000 Å is quite small except near the long wavelength extreme. Sonneborn (1984) estimates a degradation at 1300 ± 75 Å of −0.58% per year in SWP sensitivity, and a decrease at 1850 ± 75 Å of −1.27% per year. Thus a correction for the *relative* sensitivity change between 1300 and 1850 Å for post-1978 observations would make the corrected fluxes slightly redder in slope. The estimated shift for 1984 observations is only $\Delta \log f_\nu = -0.018$ at 1300 Å, relative to a normalization point at 1850 Å. For fitted temperatures at or below 25,000 K, the correction downward is 1000 K for the 1984–1985 data; at 30,000 K it would reach 1300 K for the K grid, but only ~500 K for W.

The accuracy and time dependence of the standard *IUE* flux calibration have been independently analyzed by Finley, Basri, and Bowyer (1984) using a comparison of *IUE* data on hot DA white dwarfs with models and optical data. Their results also show that both cameras have become less sensitive with time in the same manner as found by Sonneborn (1984). The increase in ultraviolet fluxes relative to optical fluxes results in an increase in the fitted temperature for a given star *from the overall energy distribution*, if the corrections suggested by these authors or Sonneborn (1984) are adopted.

On the other hand, if ultraviolet data alone are used to derive the stellar temperature, the effect of the suggested Finley *et al.* corrections is much reduced, and is again in the opposite direction, as discussed for the Sonneborn correction. The observations of the hot star PG 0112+104 were obtained in 1982.53, (July 11), so that it is appropriate to apply the Finley *et al.* numbers for 1982.5. Using values read from the curve in their Figure 3, we would revise the temperature for PG 0112+104 downward by less than 1000 K. The corrections in the long wavelength (LWR) camera are again found to be larger and more wavelength dependent than those for the SWP.

The conclusion is unchanged if we apply the Sonneborn or Finley *et al.* corrections to the entire SWP–LWR spectra and normalize to 2750–2900 Å. Since the positive flux correction is again larger at 2750–2900 Å than at the short-wavelength end of the SWP camera, the effect is to make the ultraviolet slope redder, so that a lower temperature would again be derived. The Finley *et al.* analysis did not extend to 1984–1985.

The nice agreement between the independent approaches of Sonneborn (1984) and Finley *et al.* suggests that a time-dependent correction can be applied with an uncertainty considerably smaller than the size of the correction. The errors derived by Sonneborn (1984) suggest that the temperature corrections are uncertain by about 20% of their values. However, since the possible corrections due to ultraviolet extinction are generally comparable, but in the opposite direction, we have not applied either correction to the T_W and T_K values obtained by direct fitting in Table 4.

In Figure 5, we display the 1985 reobservations of GD 358 with the SWP and LWP cameras alongside the earlier data of Koester, Weidemann, and Vauclair (1983), used in Figures 1 and 2. Exposure times for the short and long cameras were chosen to match those used by Koester *et al.* This affords not only a valuable confirmation that the object shows a hot energy distribution, but also measurements of the camera degradation of the SWP and the calibration differences between the LWR and LWP. The most noticeable result is that the LWP data are much noisier than the LWR points, and the calibration places them at significantly higher flux values. The differences between the SWP exposures are quite small, but the last exposure is not well exposed at the long end of the SWP camera where the camera degradation has been most important.

c) *Uncertainties in the Temperature Fits Due to Reddening*

Since even a visual extinction as small as $A_v \sim 0.03$ mag produces $A_{1300\,\text{Å}} \sim 0.1$ mag, the errors in the temperature fits due to interstellar reddening must be assessed. The vertical scale for interstellar gas is estimated to be only 110 pc (Kerr and Westerhout 1965). Since the DB stars evaluated here lie mostly at estimated distances of order 100 parsecs (as we shall show) and at high galactic latitude, at least a large fraction of a disk scale height of interstellar gas is typically encompassed. It is not unreasonable to assume that much or most of the interstellar material in the line-of-sight directions to some of these stars looking out of the Galaxy lies between us and the stars. It is therefore possible to estimate the column densities of neutral hydrogen in the directions of the stars by using available radio maps, and to use available correlations between the gas densities and dust extinction to derive crude upper bounds on the ultraviolet extinction on the stellar lines of sight. The typical column densities of $n_{\text{H I}}$ at high galactic latitude somewhat exceed 10^{20} cm^{-2}, which translates into a nonnegligible extinction.

The uncertainties associated with this procedure are formidable. They include the following: (1) published maps of the interstellar medium are crude in their spatial detail, and the gas distribution is known to be quite patchy on small scales; (2) we do not know what fraction of the gas is in front of the star; (3) the correlation between neutral gas and dust, specifically that between n_H and $E_{1280\,\text{Å}}$ or $E_{1850\,\text{Å}}$ is not tight. The procedure attempted here, however, should be useful in estimating the extent of the reddening uncertainty. Moreover, the emphasis upon fitting the SWP region alone reduces the magnitude of the effect.

In Table 5 maximum n(H I) column densities are estimated from the radio maps of Heiles (1975). In order to get some idea as to what fractions might be in the vicinity of the Sun, we obtained comments from Priscilla Frisch (see York and Frisch 1983) concerning lines-of-sight to specific stars (Table 5). Distances to these stars lying at high galactic latitude may be estimated by combining the approximate V magnitudes and absolute (M_v) magnitudes. The former are estimated from the apparent B (photographic) magnitudes listed for each object and the assumption that $(B-V) \sim -0.15$; derived V magnitudes are listed in Table 5. The absolute magnitudes are estimated from those given for the Koester models in Oke,

TABLE 5

POSSIBLE CORRECTIONS DUE TO ULTRAVIOLET EXTINCTION

Name	N(H I) $\times 10^{20}$ cm^{-2}	$E(B-V)$	$C =$ $\log f_{1850-1280}$[a]	V	Assumed M_v(max)	Distance (pc)	Maximum Extinction Correction to $T_{\rm eff}$
0112+104	6.70	0.11	0.06	14.81	10.42	75	+4 K[b]
1351+489	2.80	0.05	0.02	16.53	10.65	150	+1 K
GD 358	5.35	0.09	0.05	13.62	10.58	41	+3 K[b]
1115+158	2.23	0.04	0.02	16.27	10.60	136	+1 K
1654+160	12.5	0.21	0.12	16.30	10.60	138	+4 K[b]
1149−133	5.58	0.10	0.05	16.24	10.85	120	+2–3 K
GD 323[c]	2.68	0.05	0.02	13.97	10.4:	52	0[d]

[a] $C \equiv \Delta(\log f_{1850}) - \Delta(\log f_{1280}) \sim 0.706E\ (B-V)$; see text.

[b] The full correction is probably too large (see text).

[c] See discussion in Liebert *et al.* (1984) concerning this hot, DB-like object. See also § IV*c*.

[d] Correction to $T_{\rm W} \sim 30{,}000$ as estimated with pure helium models by Liebert *et al.* 1984.

Weidemann, and Koester (1985), assuming the mean of the temperatures listed for each star in Table 4 and $\log g = 8$. With the exception of GD 358 (and the peculiar object GD 323), the estimated distances are in the 75–150 pc range; at galactic latitudes exceeding 30°, at least half of these distances are included in the z components. Thus we anticipate that, for all objects except the bright GD stars, much of the line-of-sight gas and dust may be between us and the stars.

The gas column densities were converted to visual reddening using the relation

$$n_{\rm H} = 5.9 \times 10^{21}\, E_{B-V}\ {\rm mag}^{-1}\ {\rm cm}^{-2}$$

from Spitzer (1978) and a mean ultraviolet extinction curve (Seaton 1979) to derive corrections $C \equiv \Delta(\log f_{1850}) - \Delta(\log f_{1280}) \sim 0.547\ E_{B-V}$, where Δ refers to (reddened − unreddened), for the normalized *IUE* SWP flux slopes. All are listed in Table 5 along with an estimate of the upward temperature revision. The values range from as small as $C = 0.02$ for three objects to 0.12 for PG 1654+160. For stars which already have rising SWP slopes ($T_{\rm eff} > 25{,}000$ K), GD 358 and PG 0112+104, the potential effect on the temperature could be substantial. Application of the full C value listed in Table 5 (Fig. 2) would yield for GD 358 $T_{\rm W} \sim T_{\rm K} \sim$ 31,000 K; however, the recent trigonometric parallax determination ($\pi \sim 0\farcs028$; Harrington *et al.* 1985) underscores the fact that GD 358 is the nearest star in the sample. At the indicated $d \sim 36$ pc, very little of this correction may be appropriate. Moreover, the indicated M_v suggests a temperature lower than is derived by the ultraviolet (or optical) methods. The application of the full correction to PG 0112+104 may not be justified either, since the indicated distance is only ~75 pc. Thus, we expect that the temperature of this object is near 29,000–30,000 K.

The largest potential correction for a pulsating star is that for PG 1654+160, with $C \sim 0.12$. The comments from Frisch suggest that most of the line-of-sight hydrogen lies beyond 125 pc, and the star's distance is approximately that. Application of the full correction would give the star $T_{\rm K} > T_{\rm W} \sim 30{,}000$ K, though again, the full correction does not appear to be justified. For other stars in the sample near or below 25,000 K (uncorrected), the potential shifts are less than or equal to +1000 K in $T_{\rm W}$ and $T_{\rm K}$. These potential temperature increments are noted in the appropriate column in Table 5. The true width of the instability strip will, ultimately, depend on how much of the material in the directions of PG 1654+160, and conceivably PG 0112+104, is in front of the stars.

IV. CONCLUSIONS

a) The Instability Strip for Pulsating DB Stars

The temperature determinations reported herein from *IUE* data generally support the expectation of Winget and Fontaine (1983) and Winget *et al.* (1983) that an instability strip exists for pulsating DB stars. By this we mean that within a certain temperature range, most or all of the stars pulsate, and outside of that range they do not. The problems discussed at length in the last section and a paucity of hotter stars lead to great uncertainty in determining the high temperature end of the probable instability strip: it should clearly begin cooler than 34,000–35,000 K, the highest value assigned to the nonpulsating PG 0112+104 with the full reddening correction (which is probably not justified). As a compromise, we shall adopt an upper bound of 32,000 K. A lower bound on the high temperature limit is provided by the lowest assigned temperature for GD 358 from *IUE* (which has the bluest ultraviolet fluxes) at about 26,000 K. It is possible that a substantial reddening correction of PG 1654+160 would make it a hotter pulsating object than GD 358. Realistically, the high temperature boundary lies in the interval 29,000 ± 3000 K, using *IUE* temperature determinations. Using the same logic, the high temperature limit based on the optical scale should lie between 24,000 K and 29,000 K, the OWK values for the pulsating GD 358 and the nonpulsating PG 0112+104, respectively. The low temperature boundary is less sensitive to the problems outlined previously and is most likely within the interval 24,000 ± 2000 K, using *IUE* temperature determinations and is 1000–2000 K cooler with the optical scale. Of course we are a long way from establishing whether all stars within the instability region actually pulsate, but the ordering of temperatures made from using the *IUE* energy distributions (regardless of the values of temperatures assigned) is consistent with this hypothesis.

The empirical instability strip seems to lie close to that predicted by Winget *et al.* (1982) and by Fontaine, Tassoul and Wesemael (1984) using ML 3 convection (26,000–29,000 K). This finding is even more remarkable in view of the fact that the best agreement between the effective temperatures of the observed and theoretical blue edges of the instability strip for ZZ Ceti stars is also obtained if version ML 3 of the mixing length theory is used in the computations of these cooler DA white dwarf models. This suggests that, for the very first time, a calibration of the mixing length theory is possible for a whole class of stars which differ substantially in effective temperature and atmospheric composition. This is not to say, of course, that a demonstration of consistency in the mixing length formulation confirms the general theory. It is because of computational ease and the lack of a more complete theory that mixing length convection is used at all.

There are nonetheless still a few hot DB stars in the existing sample lacking *IUE* or accurate optical observations and for which reliable temperature estimates cannot yet be made: We have been unable as yet to observe PG 2246+120, for which optical MCSP fluxes give discrepant temperature estimates. The optical spectrum clearly shows this to be a hot DB star ($T_{\rm eff} \geq 18{,}000$ K). Likewise, an *IUE* observation of the well-known white dwarf GD 205 (EG 224, WD 1709+231) would be of interest. The OWK optical determination of 22,750 K suggests that this star, which does *not* pulsate (Robinson and Winget 1983), may be of value in defining the lower boundary of the instability strip. Finally, in the latter context, fast photometric observations are badly needed to test a number of these hot DB candidates for instability. Stars with temperatures near the boundaries include G270−124 (WD 0100−068), BPM 17088 (WD 0308−565), BPM 17731 (WD 0418−539), and GD 198 (WD 1612−111), in addition to some of the PG stars discussed in this paper. Many of these stars lie far south in the sky, beyond our reach.

b) *The Paucity of DB Stars with $T_{\rm eff} > 30{,}000$* K

Following this investigation, there remains only one normal DB star, PG 0112+104, with (1) a temperature likely to be above the high temperature boundary for pulsational instability, and (2) an effective temperature near or above 30,000 K. For this conclusion we emphasize that the OWK optical determination is in excellent agreement. The new *IUE* results strengthen the hypothesis of a deficiency of helium-rich white dwarfs with effective temperatures in the range 30,000–45,000 K, between the several dozen known and well-studied DB stars and the coolest of the ~20 hotter DO stars. The statistical significance of this result is assessed in relationship to the predictions of theoretical cooling curves in Wesemael, Green, and Liebert (1985). Application of the likely reddening corrections listed in Table 5 to the derived temperatures for hot DB stars does not reduce the significance of the deficiency appreciably. GD 358 and most of the previously known DB stars listed in Table 4 are brighter, closer stars, likely to have insignificant extinctions. Likewise, it does not seem likely that the discrepancy between temperatures inferred from the ultraviolet energy distribution and line spectrum of the peculiar DAB object GD 323 may be attributed to substantial (and highly peculiar) ultraviolet reddening (see Liebert *et al.* 1984).

c) *Speculation: What Is Going On with Helium-rich White Dwarfs near 30,000* K*?*

We wonder if it can be total coincidence that two kinds of peculiar, helium-rich stars also show *IUE* energy distributions very similar to the DB white dwarfs in the 25,000–30,000 K temperature region. First, there is the strange hybrid spectrum DAB star GD 323 mentioned in the previous section; note that this star is solidly established as a nonpulsator down to some 0.002 mag (Robinson and Winget 1983). We note that the quiescent nuclear-burning hypothesis of Michaud, Fontaine, and Charland (1984) and Michaud and Fontaine (1984) allows a preexisting hydrogen envelope to disappear at or below 30,000 K, predicting evolution of the spectral type of the star from DA to DB. Stars hotter than 30,000 K would be DA in type. Second, the photometric variable star AM CVn = HZ 29 (cf. Greenstein and Oke 1982) has an ultraviolet color temperature similar to those of the DB stars. While the consensus view is that this is a binary DB white dwarf, it is not clearly established that the ultraviolet energy distribution is dominated by an accretion disk, rather than by a DB white dwarf photosphere. Can either of these two objects be related to the onset of pulsation at $T_{\rm eff} \approx 30{,}000$ K or the paucity (so far) of normal helium-atmosphere degenerate stars above this temperature?

We thank Detlev Koester for providing unpublished fluxes for his models and Keith Feggins, Robert Lamontagne, and Michelle De La Pena for invaluable help with the *IUE* data. Thanks are also due to Gary Schmidt, for providing the SWP exposures for two stars, to Priscilla Frisch, for information on the local interstellar medium in the directions of several stars, and to the Astronomical Data Centers at the NASA/Goddard Space Flight Center and the University of Colorado for providing archived data. This work was supported by NASA through *IUE* grants NAG 5-38, NAG 5-343, and NAG 5-348, by the National Science Foundation grants (AST 81-15095, AST 83-43067, AST 82-18624, AST 82-08046, and AST 83-15698, by the NSERC Canada (F. W. and G. F.), and by the H. H. Lank Foundation (H. L. S.).

REFERENCES

Cassatella, A., and Harris, A. W. 1983, *NASA IUE Newsletter*, No. 23, p. 21.
Bohlin, R. C., and Holm, A. V. 1980, *NASA IUE Newsletter*, No. 10, p. 37.
Finley, D. Basri, G., and Bowyer, S. 1984, in *Future of Ultraviolet Astronomy Based on Six Years of IUE Research* (*NASA CP 2349*), p. 277.
Fontaine, G., Montmerle, T., and Michaud, G. 1982, *Ap. J.*, **257**, 695.
Fontaine, G., Tassoul, M., and Wesemael, F. 1984, in *Proc. 25th Liege Astrophysical Colloq., Theoretical Problems in Stellar Stability and Oscillations*, ed. A. Noels and M. Gabriel (Liege: Universite de Liege), p. 328.
Green, R. F., Schmidt, M., and Liebert, J. 1986, *Ap. J. Suppl.*, **61**, 305.
Greenstein, J. L., and Oke, J. B. 1982, *Ap. J.*, **258**, 209.
Hackney, R. L., Hackney, K. R. H., and Kondo, Y. 1982, in *Advances in Ultraviolet Research: Four years of IUE* (Washington: NASA), p. 335.
Harrington, R. S., *et al.* 1985, *A.J.*, **90**, 123.
Heiles, C. 1975, *Astr. Ap. Suppl.*, **20**, 37.
Kerr, F. J., and Westerhout, G. 1965, in *Stars and Stellar Systems*, **Vol. V**, ed. A. Blaauw and M. Schmidt (Chicago: University of Chicago Press), p. 167.
Koester, D. 1980, *Astr. Ap. Suppl.*, **39**, 401.
———. 1981, private communication.
Koester, D., Schulz, H., and Wegner, G. 1981, *Astr. Ap.*, **102**, 331.
Koester, D., Weidemann, V., and Vauclair, G. 1983, *Astr. Ap.*, **123**, L11.
Koester, D., Vauclair, G., Dolez, N., Oke, J. B., Greenstein, J. L., Weidemann, V., 1985, *Astr. Ap.*, **149**, 423.
Liebert, J., Wesemael, F., Sion, E. M., and Wegner, G. 1984, *Ap. J.*, **277**, 692.
McCook, G. P., and Sion, E. M. 1984, *A Catalogue of Spectroscopically Identified White Dwarfs* (2d ed; *Villanova University Observatory Contribution No.* 3).
Michaud, G., and Fontaine, G. 1984, *Ap. J.*, **283**, 787.
Michaud, G., Fontaine, G., and Charland, Y. 1984, *Ap. J.*, **280**, 247.
Oke, J. B., Weidemann, V., and Koester, D. 1984, *Ap. J.*, **281**, 276 (OWK).
Robinson, E. L., and Winget, D. R. 1983, *Pub. A.S.P.*, **83**, 386.
Seaton, M. J. 1979, *M.N.R.A.S.*, **187**, 73P.
Shipman, H. L. 1972, *Ap. J.*, **177**, 723.
Shipman, H. L., Greenstein, J. L., and Boksenberg, R. 1977, *A.J.*, **82**, 7.
Shipman, J. L., Liebert, J., and Green, R. F. 1986, *Ap. J.*, submitted.
Sonneborn, G. 1984, *NASA IUE Newsletter*, No. 24, p. 67.
Spitzer, L. 1978, *Physical Processes in the Interstellar Medium* (New York: J. Wiley), p. 156.
Strittmatter, P. A., and Wickramasinghe, D. T. 1971, *M.N.R.A.S.*, **152**, 47.
Wesemael, F. 1981, *Ap. J. Suppl.*, **45**, 177.
Wesemael, F., Green, R. F., and Liebert, J. 1985, *Ap. J. Suppl.*, **58**, 379.

Wickramasinghe, D. T. 1983, *M.N.R.A.S.*, **203**, 903.
Wickramasinghe, D. T., and Reid, N. 1983, *M.N.R.A.S.*, **203**, 887.
Wickramasinghe, D. T., and Whelan, J. A. J. 1977, *M.N.R.A.S.*, **178**, 11P.
Winget, D. E., and Fontaine, G. 1982, in *Pulsations in Classical and Cataclysmic Variable Stars*, ed. J. P. Cox and C. J. Hansen (Boulder: University of Colorado), p. 142.
Winget, D. E., Nather, R. E., and Kepler, S. O. 1984, *IAU Circ.*, No. 3932.
Winget, D. E., Robinson, E. L., Nather, R. E., and Balachandran, S. 1984, *Ap. J.* (*Letters*), **279**, L15.
Winget, D. E., Robinson, E. L., Nather, R. E., and Fontaine, G. 1982, *Ap. J.* (*Letters*), **262**, L11.
Winget, D. E., Van Horn, H. M., Tassoul, M., Hansen, C. J., and Fontaine, G. 1983, *Ap. J.* (*Letters*), **268**, L33.
York, D. G., and Frisch, P. C. 1983, in *Local Interstellar Medium, IAU Colloq. 81* (NASA CP 2345), ed. Y. Kondo, F. C. Bruhweiler, and B. D. Savage (Washington: National Aeronautics and Space Administration), p. 51.

G. Fontaine and F. Wesemael: Département de Physique, Université de Montréal, CP 6128, Montréal, Québec, Canada H3C 3J7

Richard F. Green: Kitt Peak National Observatory, P. O. Box 26732, Tucson, AZ 85726

C. J. Hansen: Joint Institute for Laboratory Astrophysics, Box 440, University of Colorado, Boulder, CO 80302

James Liebert: Steward Observatory, University of Arizona, Tucson, AZ 85721

Harry L. Shipman: Department of Physics and Astronomy, Sharp Laboratory, University of Delaware, Newark, DE 19716

Edward M. Sion: Department of Astronomy, Villanova University, Villanova, PA 19085

D. E. Winget: Department of Astronomy, University of Texas, Austin, TX 78712