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NEW RESULTS FOR HD 161796

J. D. FERNIE AND R. F. GARRISON
David Dunlap Observatory, University of Toronto
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ABSTRACT

We have redetermined the MK classification of the high-latitude supergiant HD 161796 by proper MK methods and criteria, confirming Bidelman's original classification of F3 Ib, despite the conclusion of others using different means that it must be more luminous and cooler. The explanation of this discrepancy does not seem to lie in the star being weak-lined, but we are unable to offer a satisfactory resolution to the paradox.

Several indicators confirm that $E(B-V) < 0.03$. New four-color photometry is found to agree with previous results, and together with existing Geneva photometry leads to a photometrically determined gravity and effective temperature of $\log g = 0.1 \pm 0.5$ and $T_e = 6400 \pm 200$ K.

Both the m_1 index and the spectrum suggest that HD 161796 is only slightly metal-poor, if at all.

If it is assumed that the 62 day period of the star is its fundamental period of radial pulsation, then Faulkdner's formula indicates that log g is at least 0.6 or 0.7, but within such slight variations of log g the mass is almost unconstrained. Thus the star could be of either low or high mass, the former yielding a more plausible luminosity.

Subject headings: stars: abundances — stars: individual — stars: spectral classification — stars: supergiants
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I. INTRODUCTION

HD 161796 is one of a small group of supergiants becoming known as 89 Herculis stars (Bond, Carney, and Grauer 1983) or UU Herculis stars (Sasselov 1983). They are chiefly characterized as being luminous F stars located far from the galactic plane, a property which raises interesting questions regarding their evolution: are they normal supergiants of Population I or are they post–asymptotic giant branch (AGB) stars of Population II? The evidence so far is unclear.

In a previous study of HD 161796 (Fernie 1983) it was noted that while Bidelman (1951), in first drawing attention to the star, had arrived at an MK classification of F3 Ib, almost all subsequent workers had found an absolute magnitude of between -6 and -9 (indicating at least Ia) and an effective temperature characteristic of a star several subclasses cooler. It was suggested that the classification be checked at the standard MK classification dispersion. Here we report the results of such a check.

II. MK CLASSIFICATION

A well-exposed spectrogram at 120 Å mm^{-1} was obtained with the Garrison classification spectrograph and this observatory's 0.6 m telescope on 1982 June 3 (JD 2,445,124). Good spectrograms obtained with the same instrument were available for the MK standard stars 89 Her (F2 Ib), ν Aql (F2 Ib), ι^1 Sco (F2 Ia), α Per (F5 Ib), and HD 10494 (F5 Ia), thus allowing accurate classification. This was carried out by Garrison.

As stated above, high-dispersion studies and/or photometric studies have suggested that HD 161796 is about F7 Ia. The MK dispersion spectrum, however, as illustrated by Figures 1 and 2 (Plates 00 and 00), is clearly inconsistent with such a classification. The hydrogen-line strength and the G-band development, both of which should be fairly independent of the iron abundance, definitely preclude a type much later than F3 Ib, *even if the star were weak lined.* The entire spectrum fits well at F3, as can be seen in Figure 1 by comparing it with 89 Her (F2 Ib), α Per (F5 Ib), ι^1 Sco (F2 Ia), and HD 10494 (F5 Ia). Furthermore, the hydrogen lines, the G-band, and the metallic line ratios are a very poor match for stars as late as δ CMa (F8 Ia) and γ Cyg (F8 Ib).

The luminosity classification is illustrated in Figure 2, where HD 161796 is shown in luminosity sequences at F2, F5, and F8. It clearly fits best at Ib, whether by criteria sensitive to abundances or not. It is barely possible that the luminosity class might be raised to Iab, but Ib is preferred, and there is no doubt that it is not Ia.

Bidelman's original classification is therefore upheld; we are firmly of the opinion that the MK type of HD 161796 is F3 Ib, and that this result is independent of composition effects.

III. INTERMEDIATE-BAND PHOTOMETRY

Since the conflict between the MK type of HD 161796 and the luminosity/temperature suggested by other studies remains unresolved, we have turned to previously unexplored evidence that might shed light on the problem. One such line of evidence is intermediate-band photometry. Both the Geneva photometric system and the Strömgren four-color system have been calibrated in terms of log g and T_e through theoretical model atmospheres, and photometry on both these systems is now available for HD 161796.

Burki, Mayor, and Rufener (1980) list Geneva system photometry for the star on 25 nights. These show some variation, as is to be expected since the star is known to vary by almost 0.1 mag in visual magnitude (Percy and Welch 1981; Fernie 1983). However, the averages over these nights should be quite reliable for our purposes, and these are shown in Table 1.

HD 161796 was observed on the four-color system by Perry (1969), but since he did not observe the β-index, we obtained additional $uvby\beta$ observations with our 0.6 m telescope on 1982 July 21 (JD 2,445,172.636). Both Perry's and our own results are shown in Table 2, and, given the variability of the star, we consider the agreement satisfactory. Changes of a few

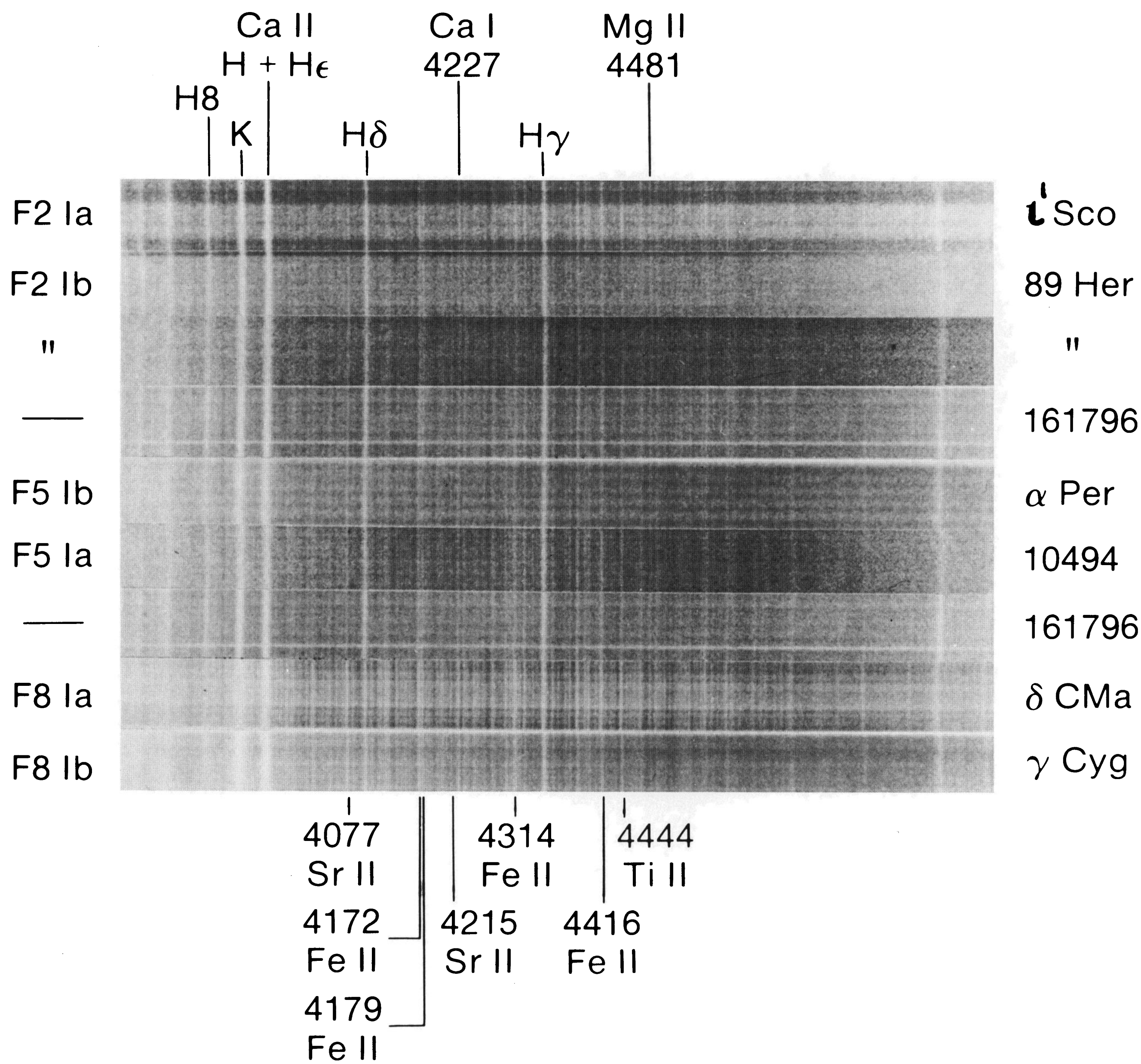

FIG. 1.—The temperature sequence for HD 161796. The hydrogen lines are too strong (see Hδ) for the later types. Line ratios, some of which are independent of abundance effects, place the star among the earlier types. F3 Ib is preferred.

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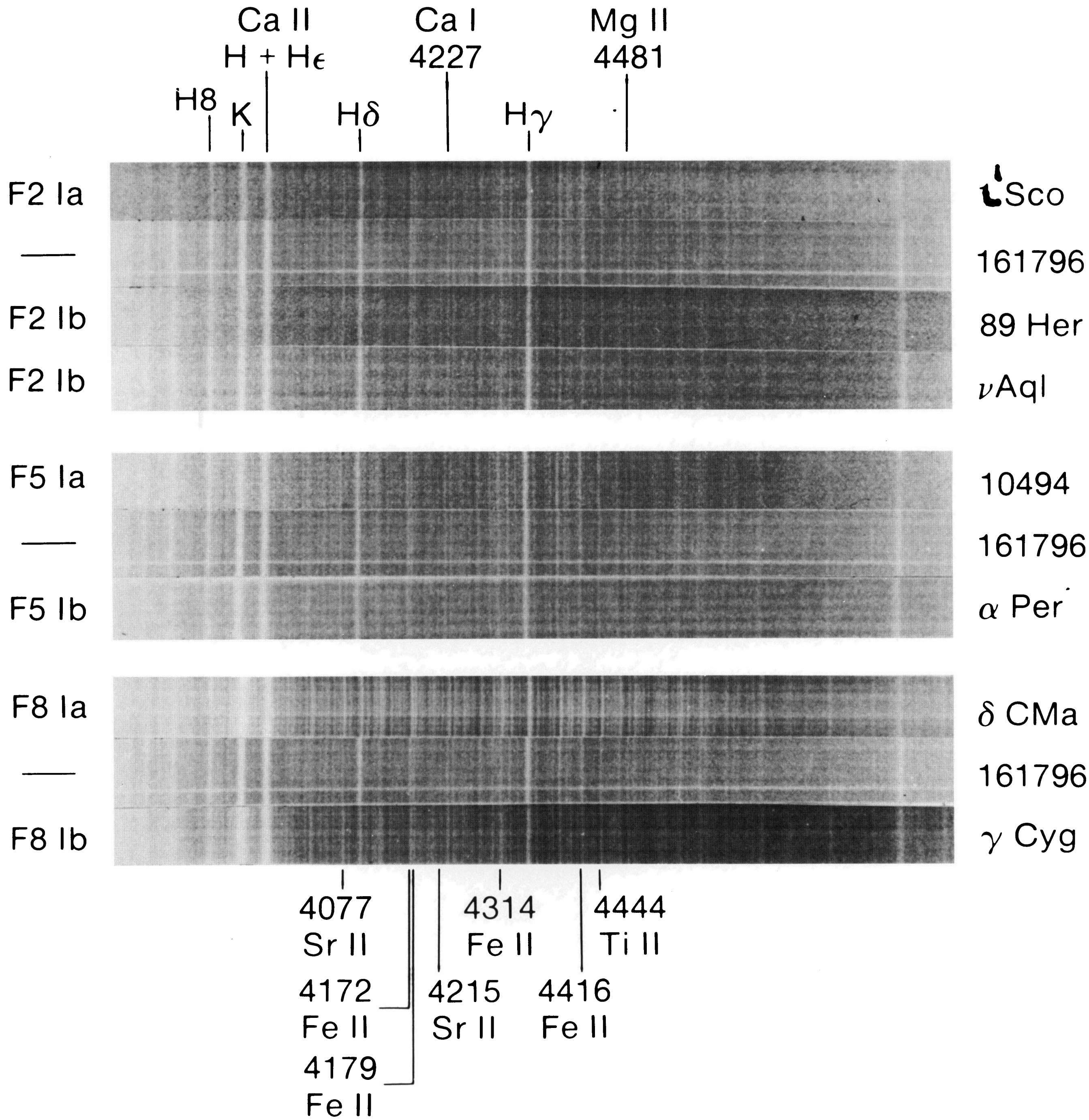

FIG. 2.—The luminosity sequences for HD 161796. All indicators favor lower luminosity than Ia at all temperature types. The type F3 Ib is preferred, independently of abundance.

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TABLE 1

GENEVA PHOTOMETRY OF HD 161796

U	V	B_1	B_2	V_1	G	m_v	d	Δ	g	m_2
2.202	0.418	0.974	1.386	1.145	1.481	7.03	1.817	0.895	0.044	−0.522

hundredths of a magnitude in the color indices will not greatly affect our efforts to distinguish between luminosity estimates differing by some four magnitudes.

Before applying these data to determining log g and T_e, we seek reassurance that no significant corrections for interstellar reddening exist. From *UBVRI* data on the Johnson system, Fernie (1983) concluded that $E(B-V) = 0.00$. This is not surprising in view of the star's galactic latitude of $+31°$, but a completely independent check is available from the work of Burstein and Heiles (1982), who give reddening contours for much of the sky based on H I column densities and galaxy counts. The resolution of their maps at low reddening is 0.03 mag, and at the position of HD 161796 we find $E(B-V) < 0.03$ mag. It is important to note that the *UBVRI* method is intrinsic while the Burstein/Heiles method is extrinsic, yet both agree. This suggests that such things as circumstellar reddening play no significant role.

We adopt zero reddening, and even if it should be 0.01 or 0.02 mag it will make little difference to our results.

Figure 3 shows an example of finding log g and T_e by means of intermediate-band photometry, in this case through a plot of the Strömgren c_1 index versus $(b-y)$. The grid of T_e and log g comes from the synthetic colors of Kurucz (1979) derived by him from his model atmospheres. Solid lines represent actually computed models, broken lines seemingly reasonable extrapolations. The cross shows the location of HD 161796 in the diagram, the size of the cross indicating observational uncertainties. The arrow is a reddening vector for $E(B-V) = 0.1$ mag; i.e., if there really is a color excess of 0.1 mag, contrary to all indications, then the cross should be relocated at the tip of the arrow. Even so, it is far removed from the position of a typical F3 Ib star, which would be at about 7400 K and log $g = 2$. For comparison one may note that classical Cepheids occupy a fairly narrow band (± 0.2 in log g) along a locus of log $g = 1.7$ in this diagram (Feltz and McNamara 1980). The photometry clearly suggests that HD 161796 has a much lower gravity of about log $g = -0.5$ and $T_e = 6200$ K. This grid of models was computed for solar composition, however, and, given the location of the star far above the galactic plane, it is conceivable that HD 161796 is metal deficient (although Searle, Sargent, and Jugaku 1963 found it to have solar composition). A similar diagram for Kurucz models computed for [Fe/H] $= -2$, although requiring more extrapolation, shows a grid moved slightly downward and to the left in Figure 3. The effect is not great, yielding log $g = -0.6$ and $T_e = 5900$ K for HD 161796, but it does increase the discrepancy with the MK type.

Geneva photometry is discussed in terms of its color indices $(U-B_2)$, (B_2-V_1), (V_1-G), and color differences d, Δ, g, and m_2. Definitions and descriptions of these terms are given by Golay, Nicolet, and North (1979), who also show the forms of the diagrams analogous to Figure 3. We have constructed such diagrams on more appropriate scales from the detailed tables of North and Hauck (1979), produced from the model atmospheres of Kurucz (1979). Each such diagram then yields a value of log g and/or T_e for HD 161796. These are collected in Table 3.

Estimates of the effective temperature were also made from the β-index, using the calibration of Schmidt (1979), from $(B-V)$ using Flower's (1977) calibration, and from $(R-I)$ using Schmidt's (1973) calibration. These too are listed in Table 3. The agreement of the various entries in this table is reasonable, except perhaps for the d/Δ and g/Δ results. However, Golay, Nicolet, and North (1979) refer to these two diagrams as the most "critical" of the collection, and by comparison with independently calibrated stars conclude that models for mid-F stars on need improving. The discrepancy may therefore not be significant, and we have simply averaged everything to obtain log $g = 0.1 \pm 0.5$ and $T_e = 6400 \pm 100$ K.

It is important to point out that the confrontation is not simply between the line spectrum (MK type) and continuous spectrum (photometry). Some of the intermediate-band indices are specifically sensitive to the line spectrum, and the β-index of course measures just one line and gives a much cooler temperature than does the MK type. Additionally, we have attempted to use the profile of the Hγ line given by Searle, Sargent, and Jugaku (1963) with Kurucz's (1979) theoretical

TABLE 2

FOUR-COLOR PHOTOMETRY OF HD 161796

y	$b-y$	m_1	c_1	β	Source
7.27	0.295	0.178	1.502	...	Perry 1969
7.145	0.312	0.163	1.450	2.667	This paper

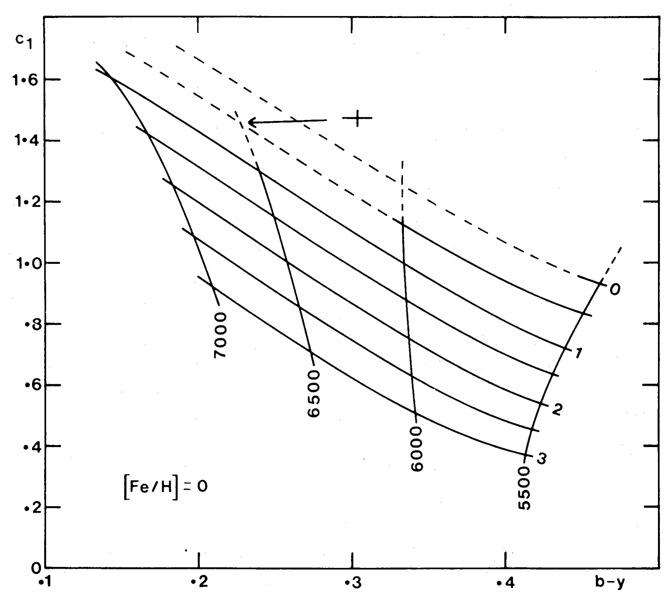

FIG. 3.—Grid of log g and T_e on the four-color system's $c_1/(b-y)$ plane, according to the model atmospheres of Kurucz. The cross marks the location of HD 161796; the size of the cross indicates observational uncertainties. The arrow is a reddening vector for $E(B-V) = 0.1$.

TABLE 3

PHOTOMETRIC DETERMINATION OF LOG g AND T_e

Photometry Type	Diagram	Log g	T_e (K)
Geneva	d/Δ	1.2	6900
Geneva	g/Δ	1.5	7200
Geneva	$d/(B_2-V_1)$	−1.5	6100
Geneva	$\Delta/(B_2-V_1)$	−0.2	6100
Geneva	$(\log g)/(U-B_2)$	−0.1	...
4-color	$(b-y)/T_e$	...	6100
4-color	$c_1/(b-y)$	−0.5	6200
4-color	β/T_e	...	6300
Johnson	$(B-V)/T_e$	...	6400
Johnson	$(R-I)/T_e$	...	6400
Line profile	Hγ	<1	6300

profiles to establish log g and T_e. We find a clear indication of $T_e \approx 6300$ K, but are unable to find a good fit for any value of log g. This is of uncertain significance, since Searle, Sargent, and Jugaku give only the profile of the line's wing, but it might well be worth more detailed study. Arellano Ferro (1983) studied the profile of Hα and found a temperature of about 6000 K, but noted that the profile was peculiar and perhaps indicative of incipient emission. Finally, we note that a photoelectric measure of the O I λ7774 triplet strength by Sorvari (1974) gave $M_v = -8.0$, quite at variance with the Ib classification. Thus there is no clear separation between line spectrum results on the one hand and continuous spectrum results on the other; the problem is some complex admixture of the two.

We are frankly unable to offer any plausible explanation for this apparent discrepancy, but do note that it is unlikely to lie in composition effects. Postulating a low metal abundance seems only to increase the discrepancy.

The m_1 index of the four-color system offers direct evidence on the star's metallicity. For reasons given below, we favor log $g = 0.6$ and $T_e = 6400$ K for HD 161796. Interpolating (and extrapolating) in Kurucz's tables, we find the theoretical values of m_1 at these values of g and T_e as a function of abundance to be 0.179, 0.104, and 0.082 for [Fe/H] = 0, −1, −2, respectively. The observed value (Table 2) is 0.17, suggesting very nearly normal abundances. This is in agreement with the findings of Searle, Sargent, and Jugaku (1963), although Abt (1960) and Luck, Lambert, and Bond (1983) have found otherwise. All these spectroscopic abundance results rest on Abt's original plate material, now a quarter-century old! Clearly a new investigation with modern data is highly desirable.

IV. PULSATION

In order to proceed further it seems necessary to consider the evidence derived from the star's variability. Fernie (1983) found photometric variability with periods of 62 and 43 days, and since the ratio of these is 0.69, which is close to the theoretically expected ratio of first harmonic to fundamental period for radial pulsation, he interpreted the variability as such. Moreover, on a so-called Petersen diagram, these data suggested a normal Population I mass for HD 161796 of about 20 $M_\odot$ or a bit less.

Others (Maeder 1980; Sasselov 1983) have suggested the pulsation is nonradial, which might better account for the complex behavior of the 89/UU Her stars as a group. We agree this may indeed be the case, but for now the evidence seems inconclusive.

If the pulsation is nonradial, then perhaps not a great deal is to be learned from it because so many modes might be involved. Radial pulsation, on the other hand, can be explored more profitably, and we do so here for at least heuristic reasons. Thus we begin with the assumption that the 62 day period of HD 161796 is its fundamental period of radial pulsation. We take as input parameters log g and T_e, guided by the results of § II, *viz.*, 0.1 ± 0.5 and 6400 ± 200 K, respectively.

No mass-luminosity law will be assumed; instead we proceed as follows:

i) Assume a mass M, and use log g to find a radius R.
ii) Compute a luminosity L from R and T_e.
iii) Use the formula of Faulkner (1977) to find a pulsation constant Q as a function of M, R, L, T_e.
iv) Compute the period, P, from the period-density relation $P = f(Q, M, R)$.

The purpose will be to see what range of masses yield a period of 62 days for gravities and temperatures consistent with those of § II.

Faulkner's formula is an interpolation device based on a large number of theoretical models by various workers. Although it is doubtless inexact, we have satisfied ourselves that it gives results to within 10% or 15% even on W Virginis stars in globular clusters.

A little numerical experimentation quickly reveals that our procedure is extremely sensitive to the adopted gravity, much less so to the adopted mass, and (in this temperature range at least) almost totally insensitive to the adopted temperature. We therefore set the latter at 6400 K; a change of several hundred kelvins will make no significant difference.

Figure 4 illustrates the periods predicted by Faulkner's formula as a function of mass for various assumed values of log g. Seeking a match to the observed period of 62 days, we see that no solution is possible for log $g < 0.6$. This is within the bounds of the photometrically determined gravity, and in any case, neither observations nor Kurucz's atmospheres nor Faulkner's formula are likely to be error-free. (We are indebted to John Lester for pointing out that at these very low gravities the Kurucz models are being pushed to the limits of reliability; a more elaborate two-dimensional code is really necessary in such cases.)

More significant is the revelation in Figure 4 that for very slight adjustments in log g one may have almost any mass one chooses to yield a particular period. Specifically, a period of 62 days can be accounted for by log $g = 0.62$ and mass = 0.6 $M_\odot$, or it can be accounted for by log $g = 0.72$ and mass = 19 $M_\odot$. In the first case we also have $M_{bol} = -4.7$ and $R = 63\ R_\odot$, while in the second case $M_{bol} = -8.2$ and $R = 315\ R_\odot$.

Strictly speaking, therefore, the star's pulsation, if interpreted as radial, does not allow a decision between high- and low-mass cases, although the low-mass case does seem more plausible in terms of luminosity and radius. (For one thing, it yields a luminosity corresponding to a Ib supergiant!)

V. SUMMARY

We have used proper MK spectra and criteria to check Bidelman's original classification of HD 161796 as F3 Ib, and find with considerable confidence that this is indeed the correct classification, even if the star should prove to be slightly metal-weak.

The reddening of $E(B-V) = 0.00$ previously adopted by Fernie (1983) on the basis of *UBVRI* colors has been checked extrinsically by the H I column density/galaxy count method

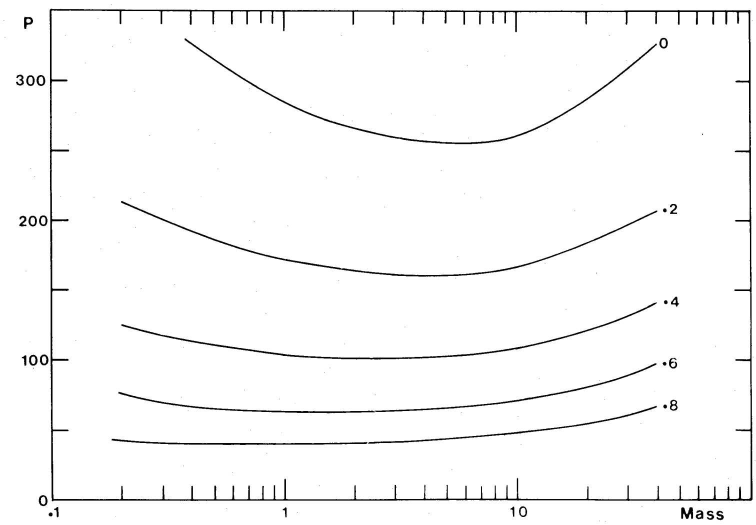

FIG. 4.—Fundamental radial pulsation period (in days) as a function of mass (in solar masses) and log g, computed from Faulkner's formula and the procedure given in the text.

of Burstein and Heiles (1982) and found to be correct, at least to within a few hundredths of a magnitude.

Published and new four-color and Geneva photometry has been assembled and used with the theoretical atmosphere models of Kurucz (1979) to determine log g and effective temperature. These data yield on average log $g = 0.1 \pm 0.5$ and $T_e = 6400 \pm 100$ K, which are at variance (by as much as 1000 K in T_e) with the MK type. They correspond more to an F7 Ia+ star.

A change in reddening will not resolve the discrepancy since the β-index (reddening free) yields the same T_e as the raw $b-y$ or $B-V$ (reddening sensitive) colors. Likewise, the reddening-free line profile of Hγ suggests the same F7–like temperature.

We note also that the strength of the O I λ7774 triplet (Sorvari 1974) suggests a luminosity much higher (or gravity much lower) than that of Ib stars. Thus the confrontation is not one between the line spectrum (MK type) and continuous spectrum (photometry), but is something more complex. We are unable to offer a resolution.

The m_1 index indicates that HD 161796 has a nearly solar composition.

An application of Faulkner's theoretical formula for pulsation period (Faulkner 1977), using $T_e = 6400$ K (but to which the formula is insensitive) and assuming that the observed 62 day period is the fundamental radial mode, shows that log g should be at least 0.6 or 0.7 but that the mass is virtually unconstrained. Thus the pulsation can be accommodated by either a Population I (19 $M_\odot$) or a Population II (0.6 $M_\odot$) star, although the latter case leads to somewhat more plausible values of $M_{\rm bol}$ (-4.7) and radius (63 $R_\odot$) than the former (-8.2 and 315 $R_\odot$). We note that an absolute magnitude of -4.7 would suit a Ib classification. In any case, we do not deny that the pulsation may in fact be nonradial.

In conclusion, we feel that the evidence on balance (including the problem of high galactic latitude) favors HD 161796 being a low-mass, post–AGB star, a result also preferred by Luck, Lambert, and Bond (1983). However, the star seems only slightly metal-weak if at all. It may be that this unusual combination is what has led to the discrepancy between MK classification and photometric parameters. We suggest that since 20 years have passed since the last high-dispersion analysis of HD 161796, the time is now ripe for a new such study.

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J. D. FERNIE and R. F. GARRISON: David Dunlap Observatory, Box 360, Richmond Hill, Ontario L4C 4Y6, Canada