THE ASTROPHYSICAL JOURNAL, 306:642–648, 1986 July 15

THREE UU HERCULIS STARS: 1984 RESULTS

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Received 1985 September 30; accepted 1986 January 10

ABSTRACT

Results of *uvbyβRI* photometry in 1984 of three UU Herculis stars, UU Her, 89 Her, and HD 161796, are reported. These data are discussed in terms of the stars' metallicities, gravities, period behavior, and evidence regarding radial and/or nonradial pulsation.

Subject headings: photometry — stars: pulsation — stars: variables

I. INTRODUCTION

The UU Herculis stars are high-latitude F supergiants which, for the most part, are difficult to distinguish spectroscopically from their low-latitude counterparts. This has posed the question of whether they are indeed normal supergiants, and if so, how they achieved their high-latitude positions, or whether they are halo population stars, and if so, how they come to mimic disk supergiants so successfully. The star 89 Herculis, for example, is such a high-latitude star, yet it serves as an MK standard for F2 Ib. These and similar questions are reviewed by Sasselov (1984), who also gives a listing of stars which are candidates for the UU Her class.

Three stars which are classic members of the class are UU Her itself, 89 Her (V441 Her), and HD 161796. UU Her is almost entirely lacking in recent (published) observations, while the other two stars have shown phenomena interesting enough to encourage further observation (see, for example, Fernie 1981; Fernie and Garrison 1984, and references therein.) Here I report *uvbyβRI* photometric observations made of all three stars in 1984. These provide not only the first such data for the prototype, UU Her, but reveal new and surprising findings for the period behavior of 89 Her and HD 161796. The color data hint that for the most part these stars pulsate nonradially, and finally, the switch to this photometric system from the *UBVRI* system allows a discussion of the stars' gravities and metallicities.

II. THE OBSERVATIONS

The observations were made with a twin-photometer system operating on 0.6 m and 0.5 m telescopes at the Dunlap Observatory. One telescope measures the variable star while the other simultaneously measures the comparison star, each photometer having two channels to allow removal of sky background by rapid chopping. The system is a photon-counting one, automated, and under computer control. Relative sensitivity is measured frequently by setting both telescopes on the same star, but no measurable drifts on a time scale of hours have been found.

HR 6123 (A5 V) was chosen as comparison star for UU Her. Absolute photometry with both telescopes on nine good nights showed it to be constant to within 0.01 mag. The magnitude and colors are given in Table 1. All *RI* data are on the Cousins system.

For 89 Her and HD 161796 the comparison stars were those used before, viz., 87 Her and HR 6656, respectively. Parameters for these stars on the present photometric system were determined as for HR 6123 and are also shown in Table 1. All data in this table have formal internal standard errors of 0.006 mag or less.

The data for the three variable stars were obtained differentially with the two telescopes as explained above, and then placed on an absolute scale by the data of Table 1. The results are contained in Tables 2, 3, and 4.

III. UU HERCULIS

The remarkable behavior of this star was pointed out nearly 60 yr ago (Gerasimovic 1928), and a suggestion that it switches pulsation between fundamental and first harmonic modes (Payne-Gaposchkin, Brenton, and Gaposchkin, 1942) predated the same suggestion (Fernie 1983) for HD 161796 by four decades. It has often been listed among the RV Tauri stars (e.g., Preston *et al.* 1983, hereafter PKSW), but I am unaware of any of these that switch between two well-defined, sharply delineated periods, and the light curve is markedly different from most RV Tauri stars (see, for example, the light curves presented by PKSW.) The hallmark of RV Tauri stars is the alternation of deep and shallow minima, the difference in depth being typically 0.5–1 mag, whereas in UU Her the phenomenon is at a level of a few hundredths of a magnitude.

PKSW found the spectral type of UU Her to be early F from the Ca II lines, but late F from the hydrogen lines, a discrepancy similar to that found for HD 161796 by Fernie and Garrison (1984).

It is worth quoting Gerasimovic (1928) on the star's behavior early this century: "In 1899 and 1900 the variable had a period close to 45 days, and the range was relatively large (1.5 mag). In 1901 (suddenly it seems) the period became much longer, between 72 and 73 days; the range was relatively small (0.8 mag), and the maxima were very long, flat, and difficult to locate. This period persisted until 1905. In 1902 the maxima became shorter, and the range increased to about a magnitude. In 1903 the maxima were of equal duration, and the range increased up to 1.5 mag. The change progressed up to 1904, when the range reached its maximum value of 1.8 or 1.9 mag. In 1905 a sudden change again occurred: the 45 day period reappeared and persisted until 1910. The amplitude during this time was moderate (1.0 mag). The data are scanty for 1909 and 1910, but it seems certain that in 1909 the range was so small that for at least a hundred days the star could be called invariable . . . ." Gerasimovic continues to trace the switching between the two periods on time scales of years up to 1927.

These early data were photographic, obtained with 1 inch

TABLE 1

DATA FOR COMPARISON STARS

Star	V	$b-y$	$m1$	$c1$	β	$V-R$	$V-I$
HR 6123	5.535	0.112	0.171	1.025	2.829	0.139	0.204
87 Her	5.090	0.685	0.528	0.339	2.619	0.587	1.092
HR 6656	5.021	0.021	0.162	1.009	2.898	0.044	0.008

(2.5 cm) and 3 inch (7.6 cm) cameras, so that "invariable" probably implies a range under a few tenths of a magnitude.

The light and color curves obtained in 1984 are shown in Figure 1, alongside and to the same scale as their counterparts obtained from *UBV* photometry by PKSW in 1961. [For comparison purposes I have transformed the $B-V$ data of PKSW to $b-y$ using $b-y = 0.33 + 0.579(B-V)$.]

It is immediately obvious that the two sets of data have different periods and amplitudes. Period finding methods show a period of 45.6 ± 0.5 days for the 1961 data, and 71.6 ± 0.3 days for the 1984 data. UU Her therefore continues its turn-of-the-century behavior in switching between periods of ~ 45 and ~ 72 days. (In 1978–1979, however, Sasselov [1983] found the star to have an 80 day period.)

The amplitude in B was about 1.0 mag in 1961, but only 0.4 mag in 1984, both at the lower end of the range found by Gerasimovic, and there is no evidence for the very flat maxima remarked on by the latter.

Of more interest are the phase relations between the light and color curves. There is a hint in Figure 1 that in 1961 the color minima preceded the light minima, while in 1984 the reverse was true. This is an important diagnostic in deciding between radial and nonradial modes of pulsation. Balona and Stobie (1979) point out that color minimum preceding light minimum is characteristic of radial pulsation, and this is seen without exception among classical Cepheids (Moffett and Barnes 1985), but that in nonradial pulsation the precedence reverses, the phase shift increasing rapidly with order of l. On this basis, and if, in fact, the data really show this effect, the 45 day pulsation would be radial, but the 72 day one an $l = 2$ nonradial mode. It would be of much interest to see a theoretical exploration of the conditions under which a star can repeatedly switch back and forth between radial and nonradial modes of pulsation. Meanwhile, the reality of the effect in UU Her needs to be confirmed. Also, radial velocity data would help check this hypothesis.

Discussion of the information on metallicity and gravity to be gleaned from the other color indices is postponed to a later section.

IV. 89 HERCULIS

The star 89 Herculis was discovered as a photometric variable by Worley (1956) and has since been observed and discussed by Percy, Baskerville, and Trevorow (1979), Burki, Mayor, and Rufener (1980), Fernie (1981), Percy and Welch (1981), and Arellano Ferro (1983, 1984), among others.

The star shows bizarre behavior. In 1977 there were regular pulsational cycles of period ~ 64 days, but essentially no radial velocity variability. In 1978 the photometric pulsation suddenly gave way to random "fluttering," which persisted through 1979, until pulsation was reestablished in 1980. The only sign of a velocity curve came during the photometric fluttering.

The light and color curves for 1984 are shown in Figure 2. The period (~ 62 days), amplitude, and mean magnitude are much as they were in 1977–1980. Again it is the phasing of the light and color curves that are of interest; as for UU Her there is a hint that the minimum of $(b-y)$ comes later than that of y, which, as described above, is indicative of nonradial pulsation. This, if established by further observation, would add to the

TABLE 2

PHOTOMETRY OF UU HERCULIS IN 1984

HJD 2440000+	V	b−y	m1	c1	beta	V−R	V−I
5873.655	9.203	0.394	0.198	0.913	2.567	0.465	0.809
5880.629	9.168	0.412	0.170	1.004	2.616	0.437	0.744
5881.633	9.158	0.402	0.165	1.025	2.633	0.446	0.779
5906.616	8.876	0.352	0.151	1.023	2.613	0.387	0.628
5912.589	8.936	0.353	0.158	1.003	2.738	0.405	0.665
5929.567	9.079	0.389	0.150	0.864	2.598	0.421	0.724
5930.562	9.085	0.382	0.185	0.975	2.630	0.432	0.767
5934.557	9.108	0.396	0.192	0.924	2.626	0.457	0.765
5937.554	9.153	0.399	0.202	1.002	2.598	0.468	0.773
5939.558	9.140	0.409	0.203	0.954	2.666	0.466	0.783
5943.582	9.145	0.409	0.206	0.921	2.642	0.464	0.763
5944.546	9.138	0.426	0.182	0.920	2.637	0.453	0.756
5948.535	9.126	0.431	0.178	1.041	2.644	0.453	0.759
5950.567	9.110	0.412	0.190	1.086	2.618	0.434	0.749
5961.517	9.081	0.366	0.210	1.029	2.665	0.465	0.727
5964.523	9.054	0.359	0.187	1.048	2.677	0.451	0.732
5965.514	9.020	0.379	0.177	0.895	2.674	0.424	0.704
5976.495	8.853	0.322	0.161	0.998	2.640	0.377	0.623
5979.502	8.853	0.323	0.163	1.100	2.653	0.372	0.628
5985.486	8.900	0.332	--	--	--	--	--
5990.535	8.962	0.360	--	--	--	--	--
5992.497	8.976	0.391	--	--	--	--	--
5993.497	8.998	0.369	--	--	--	--	--
5998.482	9.058	0.407	--	--	--	--	--
6003.480	9.146	0.418	--	--	--	--	--
6024.478	9.163	0.402	--	--	--	--	--
6029.460	9.026	0.392	--	--	--	--	--

TABLE 3

PHOTOMETRY OF 89 HERCULIS IN 1984

HJD 2440000+	V	b−y	m1	c1	beta	V−R	V−I
5873.700	5.433	0.213	0.151	1.294	2.638	0.202	0.412
5880.700	5.419	0.215	0.180	1.285	2.690	0.230	0.396
5881.687	5.430	0.223	0.171	1.318	2.689	0.241	0.390
5906.667	5.510	0.243	0.171	1.219	2.559	0.236	0.438
5912.636	5.512	0.231	0.168	1.265	2.710	0.231	0.426
5920.641	5.439	0.244	0.134	1.354	2.686	0.191	0.412
5930.612	5.408	0.218	0.169	1.286	2.667	0.259	0.385
5934.596	5.397	0.222	0.111	1.258	2.683	0.207	0.391
5937.606	5.375	0.221	0.142	1.239	2.677	0.208	0.382
5939.602	5.370	0.217	0.138	1.259	2.673	0.209	0.382
5943.617	5.377	0.214	0.137	1.166	2.664	0.201	0.380
5944.585	5.380	0.219	0.139	1.453	2.673	0.211	0.385
5948.570	5.391	0.222	0.144	1.281	2.660	0.217	0.392
5950.598	5.403	0.231	0.125	1.418	2.665	0.214	0.407
5961.554	5.472	0.233	0.159	1.192	2.679	0.227	0.413
5964.562	5.497	0.241	0.158	1.222	2.662	0.236	0.415
5965.550	5.499	0.239	0.150	1.251	2.661	0.237	0.426
5979.541	5.488	0.241	0.159	1.260	2.657	0.234	0.435
5985.534	5.482	0.252	--	--	--	--	--
5990.549	5.440	0.228	--	--	--	--	--
5992.510	5.438	0.231	--	--	--	--	--
5993.510	5.419	0.233	--	--	--	--	--
6003.495	5.342	0.216	--	--	--	--	--
6018.465	5.433	0.221	--	--	--	--	--
6024.496	5.468	0.244	--	--	--	--	--
6029.470	5.476	0.256	--	--	--	--	--

TABLE 4

PHOTOMETRY OF HD 161796 IN 1984

HJD 2440000+	V	b−y	m1	c1	beta	V−R	V−I
5873.682	6.947	0.301	0.184	1.353	2.790	0.310	0.477
5880.664	6.992	0.283	0.174	1.392	2.709	0.305	0.475
5881.670	6.996	0.281	0.192	1.358	2.705	0.303	0.477
5906.644	7.087	0.314	--	--	--	--	--
5912.615	7.065	0.291	--	--	--	--	--
5920.618	6.992	0.295	--	--	--	--	--
5929.613	6.955	0.290	0.178	1.472	2.703	0.294	0.471
5930.588	6.971	0.288	0.188	1.423	2.704	0.298	0.471
5934.580	7.014	0.286	0.197	1.466	2.707	0.340	0.497
5937.582	7.038	0.289	0.212	1.300	2.698	0.339	0.483
5939.582	7.043	0.293	0.197	1.335	2.703	0.338	0.501
5943.601	7.081	0.288	0.207	1.503	2.725	0.338	0.504
5944.569	7.089	0.275	0.226	1.322	2.718	0.355	0.501
5948.555	7.050	0.286	0.213	1.434	2.701	0.344	0.502
5950.588	7.031	0.290	0.211	1.453	2.689	0.339	0.501
5961.537	6.985	0.286	0.193	1.347	2.701	0.340	0.477
5964.549	6.992	0.276	0.216	1.385	2.700	0.335	0.474
5965.535	6.994	0.293	0.179	1.372	2.705	0.331	0.485
5976.514	6.984	0.282	0.188	1.361	2.678	0.320	0.483
5979.558	6.995	0.289	0.188	1.390	2.692	0.315	0.494
5985.548	7.007	0.294	--	--	--	--	--
5990.563	7.027	0.297	--	--	--	--	--
5992.523	7.033	0.297	--	--	--	--	--
5993.524	7.043	0.287	--	--	--	--	--
5998.495	7.066	0.300	--	--	--	--	--
6003.510	7.053	0.288	--	--	--	--	--
6018.474	6.995	0.275	--	--	--	--	--
6024.512	6.979	0.289	--	--	--	--	--
6029.485	6.986	0.288	--	--	--	--	--

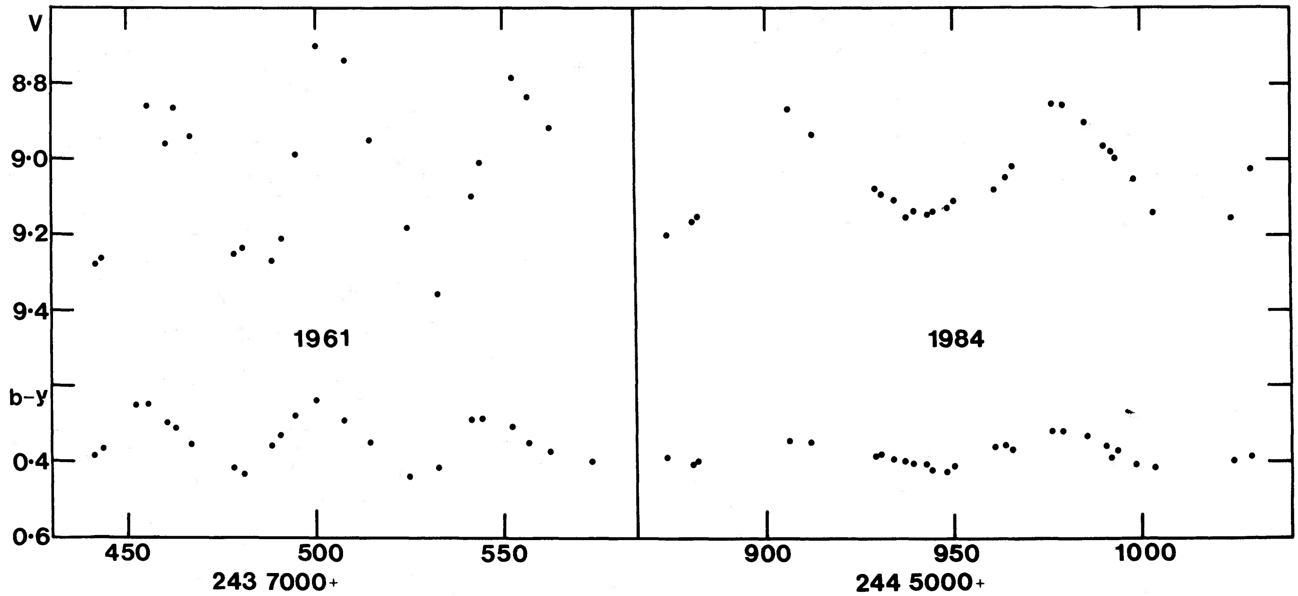

FIG. 1.—Light and color curves of UU Her in 1961 (*left*) and 1984 (*right*). Note the change in period and amplitude.

already strong evidence provided by the lack of a velocity curve accompanying the earlier light curve that we are dealing with nonradial pulsation.

An intriguing point arises as to the star's period. All investigations have found a period of 60–70 days, so 89 Her is different from UU Her and HD 161796 is not showing two distinct and quite different periods. In Table 5 are collected well-established epochs of maximum light covering nearly 30 yr gleaned from the references at the start of this section. By "well-established" I mean that the epochs are probably reliable to within 2–3 days. With the singular exception of the maximum at JD 2,444,402, all of these epochs can be fit with the ephemeris

$$\mathrm{JD}_{\max} = \underset{\pm 0.55}{2{,}443{,}317.59} + \underset{\pm 0.009}{62.646}E\ ,$$

which gives an rms deviation $(O-C)$ of 1.1 days. The ephemeris fails the JD 2,444,402 maximum by 23 days, or more than a third of a period. This maximum in 1980 was established by

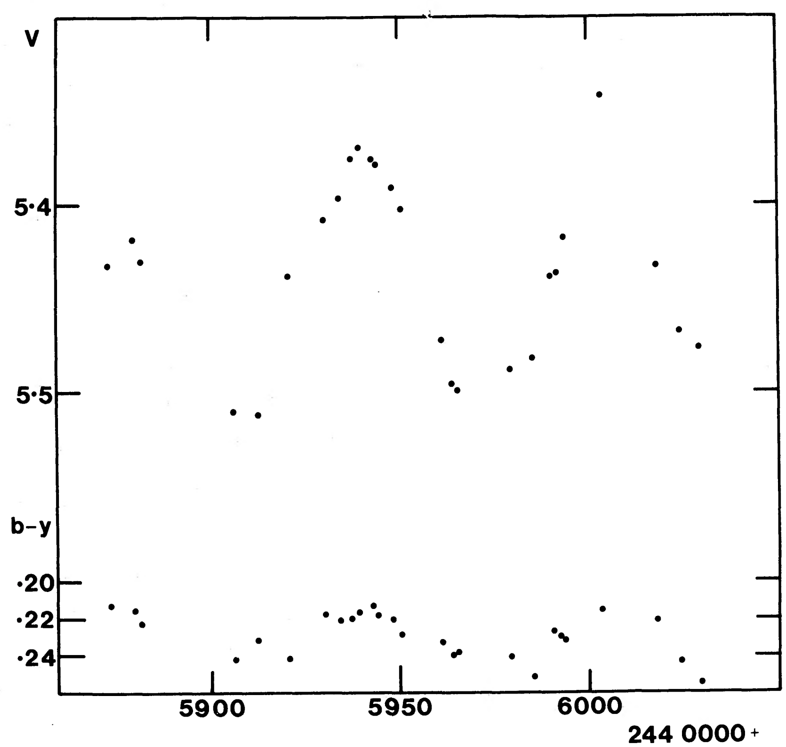

FIG. 2.—Light and color curves for 89 Her in 1984

TABLE 5

EPOCHS OF MAXIMUM LIGHT FOR 89 HERCULIS (JD_{calc} = 2,443,317.59 + 62.464E)

JD_{obs}	E	$O-C$
2,435,385.........	−127	+0.33
2,443,317.........	0	−0.59
2,443,381.........	+1	+0.95
2,443,691.........	+6	−1.37
2,444,402.........	+17	+22.52
2,445,941.........	+42	−0.07
2,446,006.........	+43	+2.46

Percy and Welch (1981), and there is no reason to doubt its reliability. It is, however, unique among the other maxima listed in just following the interval when the light curve collapsed into fluttering. The period derived from the 1980 data alone is also shorter than usual, being 58.6 days. This suggests that there is some other clock associated with 89 Her that forces the pulsation into phase-locking. When the pulsation dies out and is later reestablished at presumably a random phase, some force drives it back to the longterm phasing and period within a few cycles. Such an external clock might of course be binary motion, and indeed Arellano Ferro (1984) has already made a case for 89 Her as a binary with a 285 day period. His discussion indicates a separation of the two stars ranging from near-contact to several stellar radii, depending on the assumed masses and radii of the stars, so one might expect some influence of the companion on the pulsation of the primary. In fact, the time of periastron passage found by Arellano Ferro coincides with the middle of the fluttering episode, but on the other hand, other periastron passages would have occurred at times of observed photometric good-behavior.

A more prosaic suggestion, of course, and one that will doubtless not be overlooked, is that the observed epochs of maximum are few and it is merely coincidental that a single period can be found to fit most of them. It is open to observational test as to whether most maxima in the future continue to fit the ephemeris, while all misfitting maxima are ones following fluttering episodes.

V. HD 161796

This star is often discussed together with 89 Her, so most of the references given for the latter apply here too. Additional references are Fernie (1983) and Fernie and Garrison (1984). In the first of these HD 161796 was found to exhibit (nonsimultaneously) two well-defined periods of 62 and 43 days, followed by an interval of nonvariability. Based on the ratio of these two periods being 0.69, I suggested they represented the fundamental and first harmonic of radial pulsation since these are predicted theoretically to have that ratio if the star has a normal Population I mass. Subsequently, Fernie and Garrison (1984) found that almost any mass could be accommodated by the existing data.

Figure 3 shows the 1984 light and color curves for HD 161796. The light curve is rather different from those of 1979 and 1980 (Fernie 1983). The amplitude is about 50% larger, the extrema generally more sawtoothed, and the mean magnitude slightly (0.06 mag) but significantly brighter than in those years. (Such a long-term drift in mean magnitude has also been commented on for 89 Her by Arellano Ferro 1985.) It seems clear from Figure 3 that the cycle between about JD 2,445,900 and JD 2,445,950 has a length different from that of the next cycle. When the data for each cycle are analyzed separately, a period of ~38 days is found the first of these, and ~54 days for the next, with uncertainties of 1 or 2 days.

Burki, Mayor, and Refener (1980) had already noted a 54 day periodicity in their radial velocity data of 1978–1979, but in my discussion (Fernie 1983) I dismissed this as an alias arising from the annual observing season period and the 62 and 43 day periods. I must now retract that interpretation, since the present results involve a single straightforward cycle.

Interestingly, but perhaps coincidentally, the ratio of the present periods is to within the uncertainties the same as that of the previous two, i.e., (38/54) ≈ (43/62).

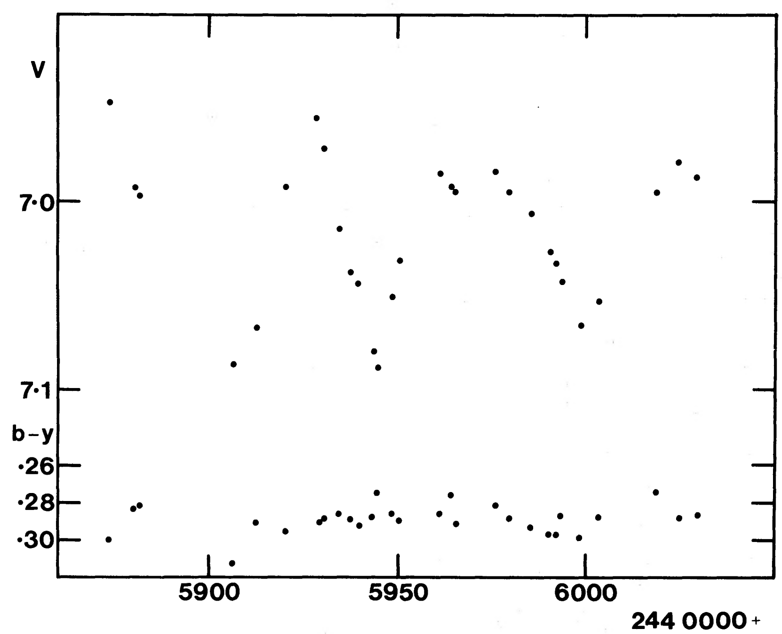

FIG. 3.—Light and color curves for HD 161796 in 1984

TABLE 6

MEAN INTRINSIC COLORS

Star	$E(B-V)$	$(b-y)_0$	$m1_0$	$c1_0$	β	$(V-R)_0$	$(V-I)_0$
UU Her........	0.00	0.38	0.18	0.99	2.64	0.44	0.73
89 Her	0.09	0.16	0.17	1.25	2.67	0.17	0.30
161796	0.00	0.30	0.19	1.40	2.69	0.33	0.49

The $(b - y)$ color in Figure 3 shows almost no correspondence with the light curve; in fact, one could say the color was constant at 0.29 ± 0.01 to within observational error. This is in contrast to the situation in 1979–1980, when, despite a lower amplitude light curve, there was a well-defined color curve. Its amplitude, however, was so low as to make phase comparisons with the light curve inconclusive.

VI. DISCUSSION

In this section I consider the three stars together and see what may be learnt about their overall properties such as metallicity and surface gravity.

Table 6 lists average values of each star's color indices corrected for interstellar reddening. The adopted color excesses are based on the extrinsic method of Burstein and Heiles (1982) so as not to place any reliance on the properties of the stars themselves. Since the latter are by definition at relatively high galactic latitudes, the corrections are small or negligible.

Figure 4 is a plot of $m1_0$ versus $(b - y)_0$, which is mostly sensitive to chemical composition. The open circles represent, from left to right, 89 Her, HD 161796, and UU Her, respectively. The closed circles represent a sample of classical Cepheids. The triangles are stars of known [Fe/H], listed by Bond (1980) and/or Luck and Bond (1985). Closed triangles are stars with $-2 < [Fe/H] < -1$; open triangles are cases with $[Fe/H] < -2$. The line is the Hyades main-sequence (Bond 1980). Any gravity effects are presumed minor, since the Cepheids and the metal-weak stars (triangles) have the same gravity range ($1 < \log g < 2$) and yet are well separated in the diagram.

There is no evidence in Figure 4 that UU Her, 89 Her, and HD 161796 have anything but normal Population I abundances, although probably one could not rule out the possibility that $[Fe/H] \approx -0.2$ or -0.3.

This conclusion is at variance with that of Dawson (1979), who found $[Fe/H] = -1.27$ for UU Her from DDO photometry. (He did not measure 89 Her or HD 161796). However, Dawson used the correlation between CN anomaly and [Fe/H] calibrated by Janes (1975) to arrive at this result. Janes's calibration was established from K giants, and its validity for early F stars is doubtful. This doubt is deepened by Dawson's results for eight classical Cepheids, for every one of which he found $[Fe/H] < 0$, almost exactly the opposite to that found from direct spectroscopic analysis by Luck and Lambert (1981). For instance, where Dawson finds $[Fe/H] = -0.61$ for SV Vul, Luck and Lambert find $+0.23$. Still, even if Dawson's result is corrected fairly substantially towards more positive values it may yet indicate a slightly negative value for UU Her, so a modest underabundance of metals in the latter cannot be ruled out.

Figure 5 is of $c1_0$ versus $(b - y)_0$ and is most sensitive to surface gravity. Symbols are as in Figure 4, with the lines of constant $\log g$ (=1 and 2, respectively) based on theoretical models by Kurucz (1979). Unfortunately, since reddening moves stars almost horizontally to the right in the diagram,

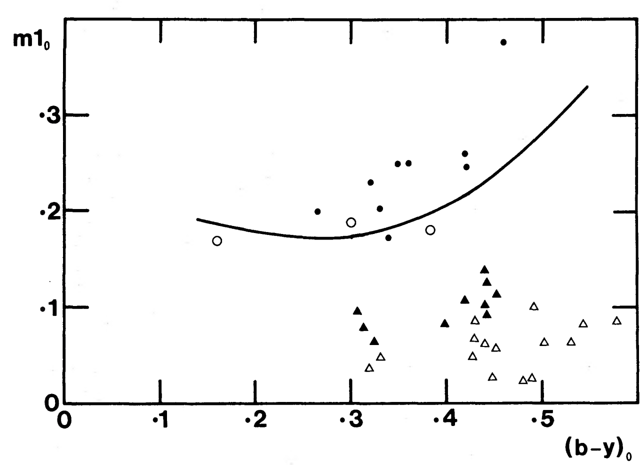

FIG. 4

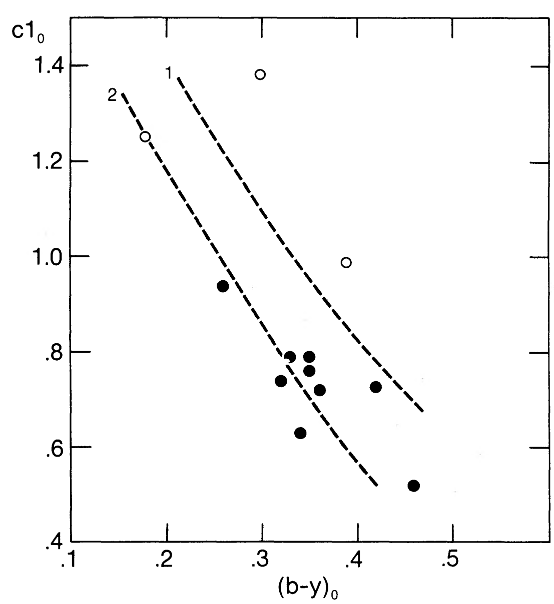

FIG. 5

FIG. 4.—The $m1_0$ vs. $(b - y)_0$ diagram, sensitive to metal abundance. The open circles depict, from left to right, 89 Her, HD 161796, and UU Her. Closed circles are classical Cepheids, closed triangles are stars with $-2 < [Fe/H] < -1$, and open triangles are stars with $[Fe/H] \leq -2$. The line represents the Hyades main sequence.

FIG. 5.—The $c1_0$ vs. $(b - y)_0$ diagram, sensitive to surface gravity. Symbols are as in Fig. 4. The two lines, based on Kurucz models, represent $\log g = 2$ and $\log g = 1$, respectively.

results are sensitive to errors in color excess. Even so, it seems reasonable to conclude that while 89 Her may have a surface gravity comparable to classical Cepheids, UU Her and especially HD 161796 have decidedly lower gravities.

This makes for an interesting correlation with period behavior. The most tightly bound star, 89 Her, shows only one period (or values close to a single period); UU Her, less tightly bound, shows two periods; HD 161796, least bound, shows a multiplicity of periods.

In conclusion, it is obvious that modern high-dispersion abundance analyses of these stars would be useful, as would continued monitoring of the light and velocity curves. In particular, more observations will be needed to check whether 89 Her really is driven into a phaselock by some external agency, and whether the suggested color/magnitude phase relations are real.

This work was supported by an operating grant from the Natural Sciences and Engineering Research Council of Canada.

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