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HR 7671: ANOTHER UU HERCULIS STAR?

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ABSTRACT

HR 7671 is an F giant or supergiant at a comparatively high galactic latitude of $-21\overset{\circ}{.}5$. Twenty years ago it was discovered to be variable, with a photographic amplitude of ~0.4 mag, but little more has been published about it since, apart from spectral classifications ranging from F1 III to F6 Ib.

During the second half of 1984, $uvby\beta(RI)_{KC}$ photometry of HR 7671 was obtained. Thirty-two observations show a range in y magnitude of ~0.3 mag, confirming the variability, but it has not been possible to derive a satisfactory period or periods. Various methods persistently show periods at ~11 and 28 days, but these fail to account fully for the variability and make little sense astrophysically.

The color indices, corrected for $E(B-V) = 0.10$, show HR 7671 to have a low surface gravity ($\log g < 1$), like UU Her and HD 161796, but also to have $[\mathrm{Fe/H}] \approx -2$, unlike other UU Her stars. This low metallicity is in agreement with a previous spectroscopic value found by McDonald.

A new MK spectral classification by Garrison, confirmed by Houk, yields F2 p (shell). This conflicts with the intrinsic colors of the star, which correspond to F7, a conflict almost identical to the case of the UU Her star HD 161796.

High-dispersion spectroscopy, radial velocities, and further photometry of this unusual but bright star, readily accessible from both hemispheres, are most desirable.

Subject headings: stars: individual — stars: variables

I. INTRODUCTION

The UU Herculis stars are a small group of F supergiants that are found at relatively high galactic latitudes. The best-known members of the group are 89 Her, HD 161796, and UU Her itself, although Sasselov (1984), in a review of the group, lists over 30 other suspects as well.

The basic interest attaching to the UU Her stars is the question of whether or not they have solar metallicities and Population I masses. If they do, they pose the question of how such young stars come to be located so far from the galactic plane; if instead they are halo population stars, there is the question of how they manage to mimic normal supergiants so well.

All members so far investigated in detail show light and velocity variations at levels typically ~0.1 mag and 10 km s^{-1}. This variability is unstable, but is usually characterized by quite long periods in the vicinity of 40–60 days.

HR 7671 is a luminous F star at a galactic latitude of $-21\overset{\circ}{.}5$. Its variability has been known for at least 20 yr, having been noted in a Bamberg survey by Strohmeier, Knigge, and Ott (1965), who found a photographic range of 0.4 mag, and who designated the star BV 592. It has been variously classified as gF4 (Wilson and Joy 1950), F1 III (Cowley 1976), F6 II (Bouw 1981), F6 Ib (McDonald 1976), and in the Case-Hamburg Northern Milky Way Luminous Stars Survey it is given as F3 Ib.[1]

McDonald found from a curve-of-growth analysis that the metal abundance is only 0.01 solar. He announced a period of "several days" for the variability and suggested that HR 7671 is probably a W Virginis star. Unfortunately, McDonald's results are available only in abstract form, and it has not been possible to obtain further details (Kraft 1984, private communication). But since a W Virginis star as bright as sixth magnitude would be a valuable find, I was prompted to undertake the photometric investigation reported here.

[1] The author is indebted to W. Bidelman for this listing.

II. PHOTOMETRY

Photometry was carried out with the 0.5 m and 0.6 m telescopes at the David Dunlap Observatory during the second half of 1984. Each telescope is equipped with an identical two-channel photometer that chops at 60 Hz between sky and sky + star to remove the background signal. Both photometers are under the control of one computer. This steps the filter wheels of the photometers in unison, triggers simultaneous 1 s integrations in corresponding filters at each telescope, reads the net photon-counted signals, and sets the next filter pair. The number of integration cycles, choice of filters, and so on, are controlled by the observer. The computer averages the data sets and finds their standard errors, reads its internal clock, and produces an on-line printout of time information (Heliocentric Julian Date, hour angle, and so on) and magnitudes and colors for each photometer, as well as differential values between photometers.

One telescope is set on the variable star, the other on the comparison star, and, provided these are reasonably close together in the sky, the system produces reliable differential photometry even through light cloud, thick haze, or aurora. Both telescopes are set on the same star at frequent intervals through the night to determine the relative sensitivities and search for drifts in these. None greater than a few thousandths of a magnitude over several hours have been found; and, to the same level of precision, the sensitivities do not depend on pointing direction.

The photometry was carried out in an eight-filter system: $uvby\beta(RI)_{KC}$.

HR 7715, an F7 V star with $V = 5.9$, was chosen as comparison star, and the four-color standard star, HR 7747 (G3 Ib, $V = 4.2$), as check star.

TABLE 1

ABSOLUTE PHOTOMETRY OF HR 7715

V	$b-y$	m1	c1	β	$V-R$	$V-I$
5.867......	0.298	0.141	0.456	2.653	0.285	0.554
0.004......	0.004	0.004	0.009	0.006	0.003	0.004

Table 1 shows results for HR 7715 derived from eight nights of absolute photometry with both telescopes providing independent measures. The errors shown are internal ones, derived from the interagreement of 33 measures over the eight nights.

Table 2 shows the results for HR 7671 derived from differential measures between HR 7671 and HR 7715 referred to the values in Table 1.

Since in the discussion which follows it will be important to know that HR 7715 is nonvariable and to have a realistic idea of the external errors of the differential photometry, Table 3 presents the individual y and $b - y$ differential measures on nine nights between HR 7715 and the check star, HR 7747. Concentrating on the y values, these being less precise than the $b - y$ ones, the internal precision derived from repeated measures on a given night range between 0.002 mag and 0.008 mag. When the set as a whole is averaged over the nine nights, individual values show a standard deviation of 0.009 mag. And since the repeated measures on a given night between HR 7671 and HR 7715 average 0.005 mag (the same as between HR 7715 and HR 7747), one may conclude that *their* night-to-night uncertainties are likewise ~0.009 mag.

TABLE 2

PHOTOMETRY OF HR 7671

HJD (2,440,000)	y	$b-y$	m1	c1	β	$V-R$	$V-I$
5880.742......	6.471	0.422	0.071	0.936	2.606	0.364	0.776
5881.735......	6.481	0.396	0.111	1.017	2.620	0.383	0.787
5906.696......	6.410	0.380	0.049	1.224	2.589	0.380	0.758
5912.670......	6.566	0.413	0.092	1.122	2.645	0.422	0.823
5920.697......	6.313	0.377	0.052	1.331	2.647	0.374	0.724
5930.656......	6.269	0.341	0.055	1.250	2.623	0.333	0.648
5932.599......	6.355	0.382	0.045	1.217	2.613	0.369	0.697
5932.633......	6.370	0.370	0.067	1.199	2.622	0.367	0.702
5932.673......	6.383	0.353	0.087	1.152	2.635	0.356	0.722
5934.635......	6.456	0.390	0.062	1.013	2.636	0.380	0.758
5937.646......	6.542	0.442	0.068	0.945	2.618	0.413	0.803
5939.644......	6.529	0.442	0.067	0.988	2.617	0.415	0.820
5943.642......	6.407	0.406	0.061	1.141	2.625	0.384	0.741
5944.615......	6.400	0.387	0.086	1.325	2.624	0.372	0.739
5948.593......	6.497	0.397	0.072	1.146	2.646	0.406	0.773
5950.612......	6.422	0.399	0.071	1.156	2.642	0.396	0.766
5961.570......	6.394	0.389	0.065	1.034	2.619	0.392	0.742
5964.591......	6.433	0.401	0.080	0.939	2.633	0.392	0.755
5965.568......	6.445	0.417	0.060	0.977	2.623	0.392	0.771
5976.532......	6.375	0.381	0.058	1.102	2.677	0.361	0.741
5979.487......	6.341	0.395	0.059	1.189	2.647	0.362	0.719
5979.527......	6.329	0.385	0.082	1.090	2.631	0.361	0.727
5979.625......	6.337	0.398	0.035	1.127	2.674	0.352	0.719
5980.508......	6.299	0.381	0.074	1.089	2.628	0.369	0.716
5985.511......	6.310	0.391	0.000	0.000	0.000	0.000	0.000
5990.517......	6.367	0.356	0.000	0.000	0.000	0.000	0.000
5992.475......	6.445	0.377	0.000	0.000	0.000	0.000	0.000
5993.480......	6.457	0.398	0.000	0.000	0.000	0.000	0.000
5998.473......	6.490	0.397	0.000	0.000	0.000	0.000	0.000
6003.463......	6.398	0.403	0.000	0.000	0.000	0.000	0.000
6024.460......	6.448	0.417	0.000	0.000	0.000	0.000	0.000
6029.447......	6.480	0.418	0.000	0.000	0.000	0.000	0.000

The important conclusion here is that a satisfactory light curve (or curves) describing the variability of HR 7671 as determined from the data of Table 2 should not show residuals averaging more than 0.01 mag.

Incidentally, since these are southern stars observed from Canadian latitudes in a rather mediocre climate, the small residuals attest to the efficacy of the twin telescope system.

II. THE PERIOD(S)

The y magnitudes in Table 2 show a range of ~0.3 mag, clearly indicating HR 7671 as a variable, and reasonably consistent with the photographic range of ~0.4 mag found by Strohmeier, Knigge, and Ott (1965). We now address the question of the period of this variability.

It will be seen from Table 2 that the star was observed at intervals sometimes as short as 1 or 2 hr. This means that in a Fourier search for periodicities it should be possible to detect periods as short as a few hours without violating the Nyquist frequency limit (Kurtz 1983). On the other hand, since the star in an intermediate bright giant or supergiant, short periods of this order are not expected.

The principal method used for the period search was the Fourier technique of Deeming (1975), although the methods of Lafler and Kinman (1965) and of Stellingwerf (1978) were also used. All the results that follow were verified by all three methods.

Figure 1 shows the power spectrum yielded by Deeming's method for periods in the range 0.8–65 days (other ranges were also searched, altogether covering 0.05–100 days; the present diagram illustrates the principal results). The lower panel is the so-called window function; its single sharp peak is at the frequency of 1/(one sidereal day), illustrating the fact that most of the data were obtained at the rate of one observation per night.

The upper panel of Figure 1 shows the complex spectrum resulting from the star's variability and the aliases arising from this and the observing frequency. Peaks labeled 1, 2, and 3 correspond to periods of 28.4, 11.8, and 5.3 days, respectively. Those labeled 4–9 are aliases arising from the first three and the 1 day observing frequency, as Table 4 shows, while some of the lesser peaks can be identified as higher order aliases as well.

We thus focus attention on the three longer periods. The 28-day period seems reasonably certain; its amplitude of 0.20 mag accounts for most of the observed 0.3 mag variability, and prewhitening the data of Table 2 for this period (see Fig. 2) reduces the rms scatter from 0.074 mag to 0.041 mag.

TABLE 3

DIFFERENTIAL PHOTOMETRY
HR 7747–HR 7715

HJD (2,440,000+)	y	$b-y$
5965.576	−1.564	0.338
5976.540	−1.581	0.342
5979.519	−1.572	0.334
5980.516	−1.550	0.341
5985.521	−1.571	0.341
5990.524	−1.571	0.339
5992.481	−1.560	0.333
5993.486	−1.573	0.333
6003.469	−1.562	0.337
Mean	−1.567	0.338

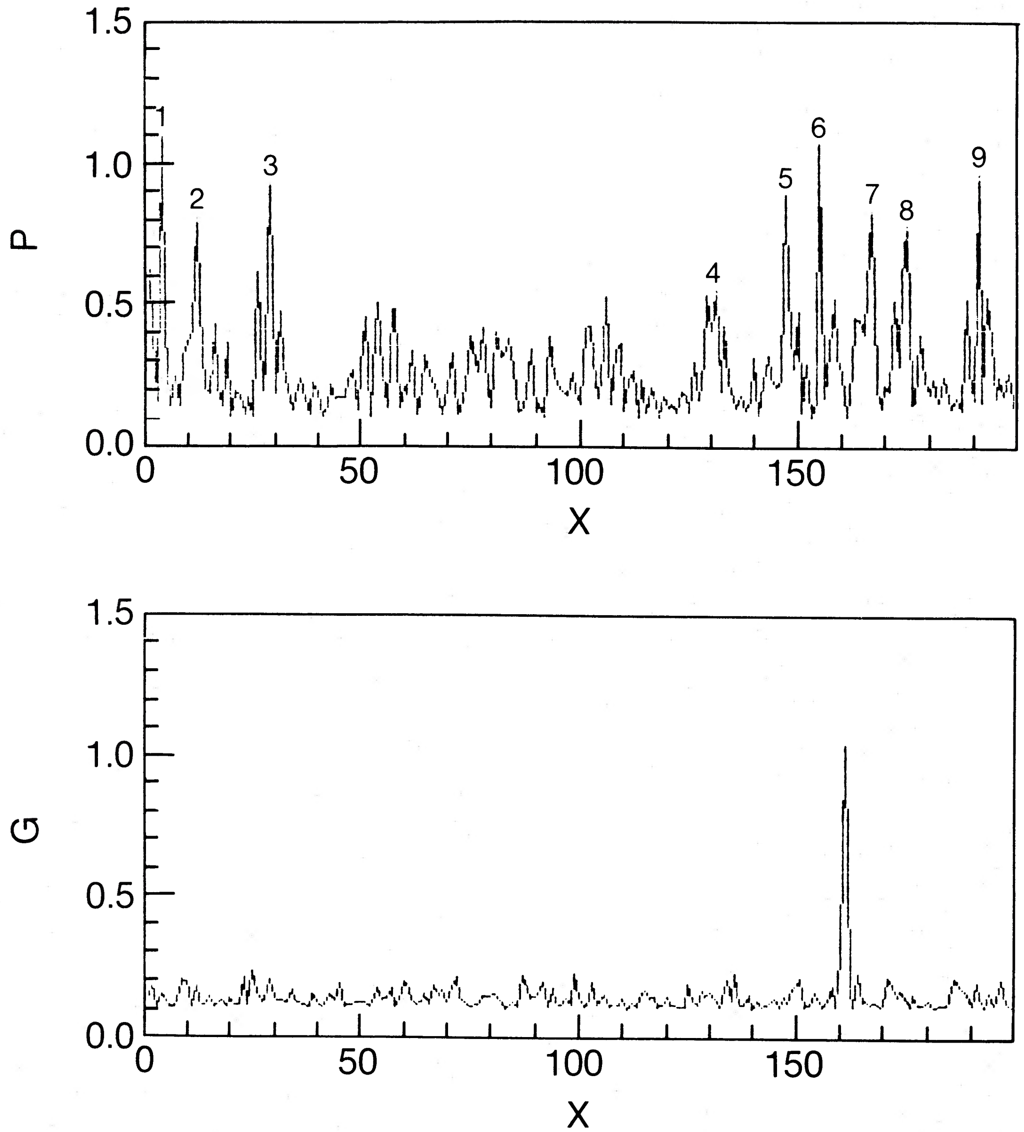

FIG. 1.—Power spectrum by Deeming's method of the *y* magnitudes listed in Table 2. Ordinate is relative power, while *X* is related to frequency by $\nu = 0.00921 + 0.00617X$. Period range covered here is (*from left to right*) 65–0.8 days. Lower panel is the window function, and its single peak shows the one-cycle-per-day observing frequency. In upper panel, peaks 1–3 are stellar, while 4–9 are aliases arising from these and the observing frequency.

Curiously, however, if the prewhitened data are subjected to another spectral analysis, the 5 day period vanishes. But reversing the procedure (i.e., first prewhitening for the 5 day period) does not eliminate the 28 day period, and leads to a higher rms scatter (0.057 mag). This, and the fact that there is a rough but suspicious commensurability present ($2 \times 11.8 + 5.3 = 28.9$), suggests the 5 day period may be an artifact, although just how it arises is not clear. In either case, the 11 day period remains. (There is also evidence for some power at a period near 60 days, but its behavior is like that of the 5 day period, vanishing when the data are prewhitened for the 28 day case.)

TABLE 4

FREQUENCIES OF PEAKS IN POWER SPECTRUM

Peak	Frequency	Frequency Differences	Periods
1.........	0.035	...	28
2.........	0.084	...	11
3.........	0.187	...	5
4.........	0.815	1.002 − 0.187	5, 1
5.........	0.918	1.002 − 0.084	11, 1
6.........	0.967	1.002 − 0.035	28, 1
7.........	1.037	1.002 + 0.035	28, 1
8.........	1.086	1.002 + 0.084	11, 1
9.........	1.189	1.002 + 0.187	5, 1

If the data are prewhitened for the 28 day period and then phased on the 11 day period, one obtains Figure 3. The amplitude of this mode is 0.10 mag, and the rms scatter now reduces to 0.026 mag. This is still above the expected value of 0.01 mag or less established in the previous section, however, and since the 5 day period vanished with the 28 day one, there is no obvious further period with which to continue.

If one first prewhitens the data for the 5 day period, then the 28 day period, and finally the 11 day period, there is no improvement in results. In fact, there is a marginal worsening

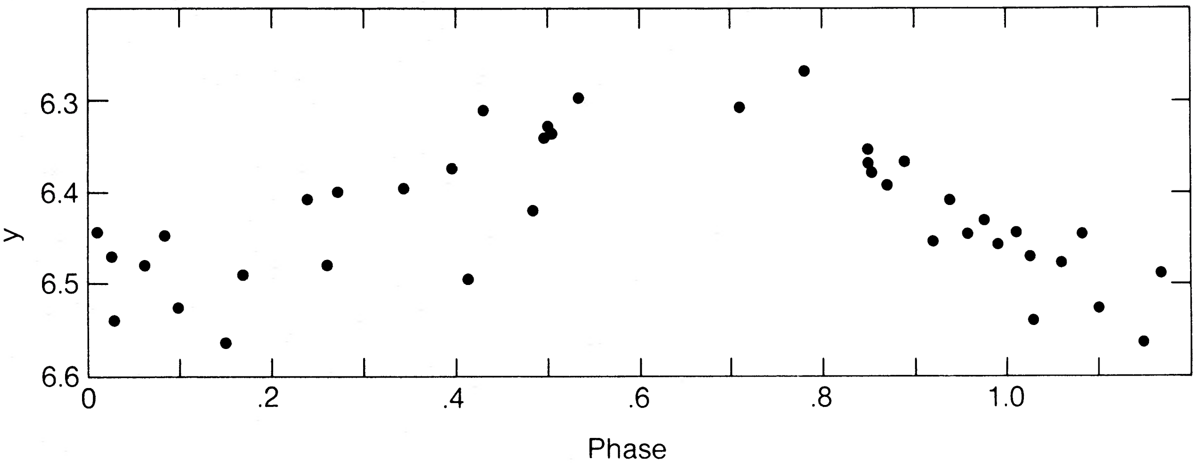

FIG. 2.—The y magnitudes of Table 2 phased on a period of 28.4 days. No prewhitening has been done.

compared to the 28 and 11 day periods alone. This, too, militates against the reality of the 5 day period.

In any case, although the 28 and 11 day periods appear consistently, they make no astrophysical sense unless some exceedingly unlikely combination of modes is present.

One concludes that additional data are needed to unravel the periodicities present in HR 7671.

IV. COLORS

Table 2 also contains color index data for HR 7671. (Dummy values of zero are shown for later entries when the star became too low in the west at evening twilight to allow complete measurements.)

Since the star has such a low amplitude of variability, it will suffice to take averages of the color indices as indicative of the mean colors. These are shown in Table 5.

Because the star is peculiar and probably metal weak, I have used only an extrinsic method for estimating its color excess; viz., the method of Burstein and Heiles (1982) based on galaxy counts and H I column densities. Given the fairly high latitude of HR 7671, this method should be quite reliable. It gives 0.10 mag as the upper limit for $E(B-V)$. This leads to the intrinsic colors also shown in Table 5.

Plots of $(b-y)_0$ versus spectral type, β versus spectral type, and $(R-I)_0$ versus spectral type lead to spectral types of F7, F7, and F8, respectively, from the colors of HR 7671. The colors are therefore mutually consistent, and, in particular, the agreement between β, which is reddening independent, and the other two, which are not, indicates that the estimated color excess is not far wrong. However, the colors are at variance with some of the spectral types quoted in the introduction, a point I return to in the following section.

TABLE 5

MEAN COLORS OF HR 7671

$b-y$ $(b-y)_0$	m1 $\mathrm{m1}_0$	c1 $\mathrm{c1}_0$	β	$V-R$ $(V-R)_0$	$V-I$ $(V-I)_0$
0.394.........	0.068	1.113	2.630	0.379	0.747
0.32..........	0.09	1.10	...	0.33	0.63

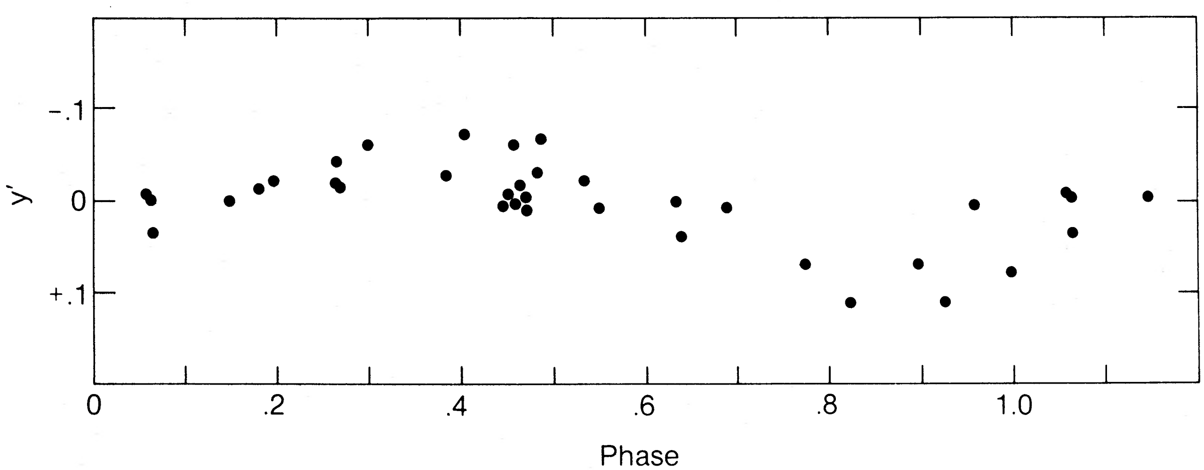

FIG. 3.—The y magnitudes after prewhitening for the 28.4 day period, phased on a period of 11.8 days. Note that the scatter, expected to average 0.01 mag, remains unacceptably large.

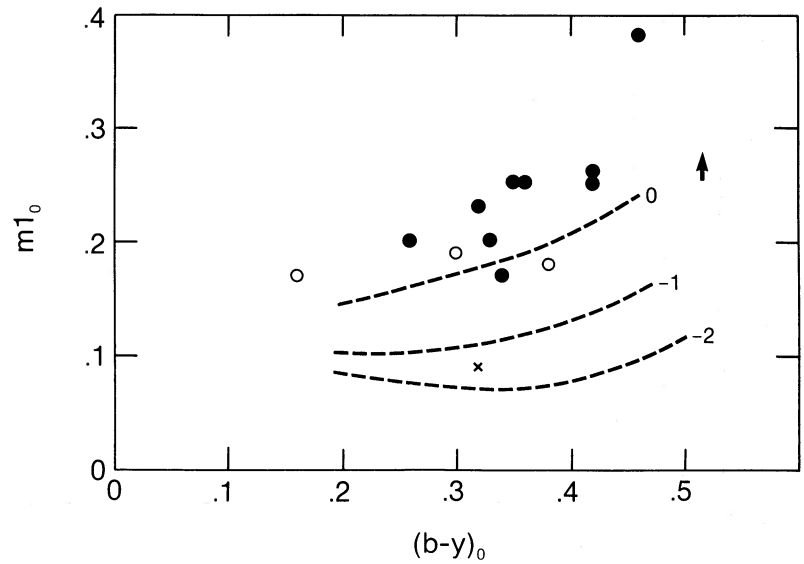

FIG. 4.—The $m1_0$ vs. $(b - y)_0$ diagram, mostly sensitive to abundance effects. Closed circles are classical Cepheids, open circles (*fron left to right*) are the three UU Her stars 89 Her, HD 161796, and UU Her, while the cross represents HR 7671. The three lines are based on theoretical Kurucz models for [Fe/H] = 0, −1, and −2, and log $g = 2$. For log $g = 1$ the grid should be moved upward by about the length of the arrow. The m1 index of HR 7671 thus supports an earlier spectroscopic estimate of [Fe/H] ≈ -2.

The m1 and c1 indices contain other evidence. Figure 4 shows $m1_0$ versus $(b - y)_0$. The closed circles are classical Cepheids, based on the photometry of Feltz and McNamara (1980); the open circles represent unpublished photometry (Fernie, in preparation) of the UU Her stars 89 Her, HD 161796, and UU Her itself. The cross represents HR 7671. This diagram mainly illustrates the effects of metal abundance, and the three lines, based on theoretical models by Kurucz (1979), are drawn for [Fe/H] values of 0, −1, and −2, respectively. The available grid of models does not cover exactly the range needed here, and the lines actually refer to models with log $g = 2$. One or two other points in the grid suggest that the lines should be moved upward in the diagram by about the length of the arrow for log $g = 1$.

Despite the uncertainty in the theoretical models, the data clearly indicate that while UU Her, 89 Her, and HD 161796 seem to have solar abundances, HR 7671 is underabundant in metals to an extent consistent with McDonald's spectroscopic estimate of −2.

Figure 5 is a plot of $c1_0$ versus $(b - y)_0$ and is mostly indicative of surface gravity. The symbols are the same as in Figure 4, and the lines from Kurucz's models are for solar abundances and log $g = 1$ and 2, respectively. HR 7671 clearly has a lower gravity than most Cepheids; more so, in fact, than the diagram suggests, since the theoretical grid for [Fe/H] = −2 would be downward and to the left of the one shown in the diagram for solar abundances. The theoretical models, however, are too sparse and uncertain to offer a firm value of log g. Nevertheless, it seems that log $g < 1$.

V. SPECTRAL TYPE

In view of the considerable range of published spectral types for HR 7671, most of which were derived from spectral dispersions other than that defining the MK systems I asked Robert Garrison to obtain a spectrogram at the proper MK dispersion and reclassify the star. This he did, finding a result of F2 p (shell).

Nancy Houk (1985, private communication to Garrison), independently and from a plate of her own, agrees that the star is early F, a later type being precluded by the G band, and that the hydrogen lines, as well as λ4481 and λ4030, appear shell-like. She remarked that HR 7671 seems a milder version of HD 101584, a southern star that might bear investigation.

An early F spectral type is at variance with the colors of the star as described above, and also the β index is normal for the color. Both these discrepancies are reminiscent of—indeed, almost identical to—the situation for the UU Her star, HD 161796, discussed by Fernie and Garrison (1984).

VI. SUMMARY AND CONCLUSIONS

It has been verified that HR 7671 is variable, with a visual amplitude of ~0.3, but, while periods of 28.4 and 11.8 days seem present, these are inadequate to account completely for the variability and would be difficult to interpret astrophysically.

The color excess of the star is estimated to be 0.1 mag or less, and the resulting values of $(b - y)_0$ and $(R - I)_0$, as well as of β, correspond to an F7 star. Proper MK classification, however, gives F2 p with shell features. The intrinsic value of the m1 index suggests [Fe/H] ≈ -2, in agreement with an earlier spectroscopic estimate by McDonald (1976), while the intrinsic c1 index indicates log $g < 1$.

The very low gravity and the shell features suggest the presence of considerable mass loss, which may, particularly if episodic, introduce complications into the periodicity.

Clearly, a full-scale, high-dispersion spectroscopic study of HR 7671 (including radial velocities) would be useful, and further photometry will be needed to unravel the period structure. Photometry in the Geneva or Walraven system, or both, would be helpful.

The question of whether or not HR 7671 should be considered a UU Her star remains open. Its early F spectral type but later F colors, low gravity, and curious period behavior are reminiscent of UU Her stars, but it seems to be of significantly

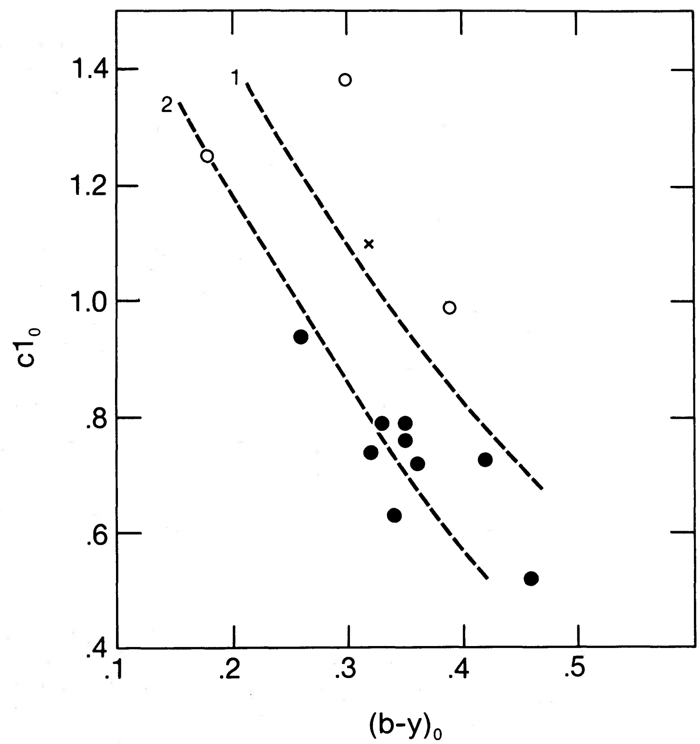

FIG. 5.—The $c1_0$ vs. $(b - y)_0$ diagram, mostly sensitive to surface gravity. Symbols are as in Fig. 4. The two lines are based on theoretical Kurucz models for log $g = 2$ and 1, respectively, and solar abundances. The grid would be depressed in the diagram for metal-weak models. Thus, like the UU Her stars HD 161796 and UU Her, HR 7671 appears to have log $g < 1$, especially since it is decidedly metal weak.

different chemical composition, and the principal periods are much shorter than found among UU Her stars.

It is a pleasure to thank Robert Garrison and Nancy Houk for determining the MK type of HR 7671, and Christine Clement and Tom Wells for running the photometric data through their VAX program of period searching by Stellingwerf's method. Support in the form of an operating grant from the Natural Sciences and Engineering Research Council of Canada is also gratefully acknowledged.

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