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ASTRONOMY AND ASTROPHYSICS

Intercontinental simultaneous survey of the unique cepheid HR 7308 in photometry and radial velocity

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Summary. A simultaneous monitoring in photometry and radial velocity was organized in August 1984 on the unique cepheid HR 7308 (V473 Lyr). The data were obtained by using ten telescopes located in six different countries in Europe and North America.

Three different versions of the Baade-Wesselink method have been applied and the results ($50 \pm 15\,R_{\odot}$, $41 \pm 11\,R_{\odot}$, $32 \pm 10\,R_{\odot}$) are in favour of a mean radius larger than $30\,R_{\odot}$. The photometric analysis confirms that the star has a normal solar abundance.

HR 7308 is most probably a classical cepheid pulsating in the second (or higher) overtone. However, the possibility that the star is a Population II cepheid and/or that it is pulsating in the fundamental mode or the first overtone cannot yet be ruled out definitively.

Key words: stars: HR 7308 – stars: cepheids – stars: variable – stars: abundances – photometry – radial velocities

1. Introduction

HR 7308 (HD 180583, V473 Lyr) has interested many observers during the past decade, because this cepheid is exceptional in several aspects. Its essential characteristics, summarized from the papers by Breger (1969, 1980, 1981), Percy et al. (1979), Percy and Evans (1980a, b), Percy and Ford (1981), Burki and Mayor (1980a, b), Burki et al. (1982), Burki (1984), Henriksson (1980, 1983), van Genderen (1981), Fernie (1982), Arellano Ferro (1984), Stellingwerf (1984), Balona (1985), Simon (1985), Auvergne (1986), are the following:

1) The pulsation period, $1^{d}490975 \pm 0^{d}000001$., was stable at least during the last seven years. The constancy of the period implies the constancy of the mean radius.

2) The amplitude of pulsation varies by at least a factor of 15. In radial velocity, the last maximum total amplitude was $35\,\mathrm{km\,s^{-1}}$ (June, 1985) and the last minimum total amplitude was $2.3\,\mathrm{km\,s^{-1}}$ (Jul.-Sept. 1982). The time elapsed between the last two maxima (August 1981 and June 1985) is about 1400d. This periodic, or at least quasi-periodic, variation of the amplitude is not due to the beating between two oscillation modes of closely spaced frequencies.

3) The shape of the radial velocity curve, and certainly also that of the light curve, is simply sinusoidal when the amplitude is minimum and becomes asymetrical with increasing amplitude. Thus, HR 7308 offers the possibility of studying, in the same star, the variation of the shape of velocity and light curves with the intensity of the non-linear effects acting on the driving mechanism of the pulsation.

4) In the HR diagram, the star lies clearly to the red of the instability strip.

5) The mean value of the radial velocity curve does not vary significantly with time. Thus, the variation of amplitude is probably not due to the existence of a companion.

6) The star shows normal solar abundancy.

7) The various possible mechanisms invoked to explain the amplitude variation are:

i) a star entering or leaving the instability strip (Burki and Mayor, 1980),

ii) an interaction between pulsation and convection (Stellingwerf, 1984),

iii) an instability of the limit cycle (non-linear dynamical calculations by Auvergne (1986)).

8) Concerning the mean radius R_0, absolute magnitude M_v and distance d to the sun, important discrepancies can be noted between the determinations: Burki et al. (1982) obtained $R_0 = 34 \pm 5\,R_{\odot}$, $M_v = -3.1 \pm 0.5$ and $d = 810^{+100}_{-220}$ pc, and Arrelano Ferro (1984) determined $R_0 = 20\,R_{\odot}$, $M_v = -1.8$ and $d = 380$ pc.

From this discrepancy on the value of R_0 originate diverging conclusions on the pulsation mode of HR 7308: under the hypothesis that the star is a classical (i.e. massive) cepheid, a radius larger than $30\,R_{\odot}$ implies a (radial) pulsation in a high overtone (at least the 2nd one), when a value of R_0 around $20\,R_{\odot}$ implies a normal pulsation in the fundamental mode. The debate is

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Table 1. Differential magnitude V measurements with respect to HR 7280. The origin of time is t_0 = HJD 2445900. The authors are Schmidt (SC), Percy and Coffin (PE), Sasselov (SA), Fernie (FE), Arellano Ferro (AF) and Szabados (SZ)

$t-t_o$	ΔV	Author
21.624	-.143	SC
21.638	-.153	SC
24.692	-.184	SC
24.712	-.195	SC
24.735	-.205	SC
24.820	-.247	SC
24.888	-.281	SC
24.913	-.290	SC
25.606	-.123	SC
25.640	-.117	SC
25.673	-.111	SC
25.708	-.106	SC
25.740	-.096	SC
25.772	-.091	SC
25.804	-.091	SC
25.839	-.092	SC
25.866	-.095	SC
25.891	-.091	SC
26.598	-.288	SC
26.633	-.275	SC
26.672	-.263	SC
26.701	-.256	SC
26.765	-.226	SC
26.799	-.211	SC
26.836	-.201	SC
26.866	-.200	SC
26.890	-.176	SC
29.581	-.308	PE
29.629	-.311	PE
29.655	-.270	PE
29.677	-.255	PE
30.607	-.175	PE
30.630	-.161	FE
30.659	-.190	PE
30.680	-.209	PE
32.344	-.284	SA
32.580	-.281	FE
32.581	-.264	PE
32.617	-.223	PE
32.618	-.268	FE
32.649	-.248	PE
32.660	-.258	FE
32.667	-.249	PE
34.615	-.092	FE
34.620	-.096	PE
34.640	-.112	PE
34.673	-.063	PE
34.722	-.113	PE
35.687	-.206	AF
36.605	-.175	SC
37.622	-.086	FE
39.621	-.187	FE
39.660	-.235	AF
41.367	-.278	SZ
41.373	-.293	SZ
42.665	-.248	AF
43.735	-.095	AF
44.797	-.149	AF
45.673	-.229	AF
45.734	-.230	AF
46.699	-.089	AF

Table 2. Differential $b-y$ measurements with respect to HR 7280. The origin of time is t_0 = HJD 2445900. The authors are Schmidt (SC) and Fernie (FE)

$t-t_o$	$\Delta(b-y)$	Author
21.624	.128	SC
21.638	.131	SC
24.692	.116	SC
24.712	.115	SC
24.735	.114	SC
24.820	.098	SC
24.888	.085	SC
24.913	.082	SC
25.606	.138	SC
25.640	.141	SC
25.673	.144	SC
25.708	.151	SC
25.740	.145	SC
25.772	.141	SC
25.804	.141	SC
25.839	.145	SC
25.866	.148	SC
25.891	.142	SC
26.598	.094	SC
26.633	.094	SC
26.672	.104	SC
26.701	.104	SC
26.765	.104	SC
26.799	.112	SC
26.836	.127	SC
26.866	.123	SC
26.890	.124	SC
30.630	.106	FE
32.580	.099	FE
32.618	.102	FE
32.660	.101	FE
34.615	.137	FE
36.605	.117	SC
37.622	.148	FE
39.621	.118	FE

Table 3. Radial velocity measurements. The origin of time is t_0 = HJD 2445900. The measurement identified by an asterisk is due to Sasselov. The other measurements were obtained by Burki and Ischi

$t-t_o$	V_r
24.371	-7.14
24.396	-6.68
24.437	-6.66
24.473	-6.82
24.501	-6.90
24.518	-7.18
24.539	-7.43
24.555	-7.75
24.570	-7.89
24.581	-8.14
24.588	-8.19
24.595	-8.33
25.332	-17.98
25.352	-17.97
25.379	-16.99
25.393	-16.43
25.410	-16.29
25.432	-15.06
25.440	-15.61
25.468	-14.27
25.482	-13.97
25.512	-13.23
25.537	-12.71
25.555	-12.06
25.567	-11.90
25.587	-11.68
25.596	-11.39
26.319	-18.89
26.334	-19.30
26.348	-20.02
26.364	-21.12
26.386	-21.94
26.414	-22.72
26.438	-23.00
26.458	-23.81
26.472	-23.88
26.506	-23.68
26.540	-23.93
26.559	-23.92
26.591	-23.23
26.602	-23.00
27.315	-7.31
27.331	-7.08
27.394	-6.60
32.427 *	-23.60
32.587	-23.29
32.608	-22.94
33.507	-7.36
33.581	-9.43
33.606	-10.11
37.554	-10.08
37.592	-9.44

important since no other classical cepheid is known to pulsate in the 2nd (or higher) radial overtone. For this reason, we tried to organize this simultaneous intercontinental monitoring of HR 7308 in photometry and radial velocity, and the results of this survey are presented in this paper.

2. Observations

Tables 1 and 2 present the list of the differential photometric measurements in magnitude V and colour index $b-y$. They are given with respect to the comparison star HR 7280 (F5V). These data have been obtained by E.G. Schmidt (noted SC in the Tables) with the 0.76 m telescope at Behlen Observatory (USA), by J.D. Fernie (FE) with the 0.6 m and 0.5 m telescopes at the David Dunlap Observatory (Canada), by J.R. Percy and B. Coffin (PE) with the 0.4 m telescope at the University of Toronto campus, by A. Arellano Ferro (AF) with the 1.5 m and 0.8 m telescopes at San Pedro Mártir Observatory (Mexico), by D. Sasselov (SA) with the 0.6 m telescope at the Rozhen National Observatory (Bulgaria) and by L. Szabados (SZ) with the 1 m telescope of the Konkoly Observatory at Piszkésteto Mountain (Hungary).

The radial velocity measurements (see Table 3) have been collected by G. Burki and E. Ischi using the spectrovelocimeter CORAVEL and the 1 m telescope of the Geneva station at the Haute-Provence Observatory (France) and by D. Sasselov using the Coudé spectrograph of the 2 m telescope at NAO-Rozhen (Bulgaria).

The total numbers of measurements obtained during the range HJD 2445921 – 2445947 are 61 differential ΔV magnitude, 35 in $\Delta(b-y)$ colour and 52 in radial velocity. These data have been fitted by least squares to a function of the form

$$f(t) = A_0 + \sum_{k=1}^{3} A_k \cos(2\pi k\nu(t-t_0) + \Phi_k) \quad (1)$$

The period $P = \nu^{-1}$ given in the Introduction and the time origin $t_0 =$ HJD 2445900 have been adopted. The values of A_0, $A_k (k = 1, 2, 3)$ and Φ_k are given for the light, colour and velocity curves in Tables 4 (time interval $t - t_0 = 21$ to 28) and 5 ($t - t_0 =$ 21 to 47). Table 5 also gives the precision of the measurements, estimated from the residual standard deviations σ_{res} of the data around the fitted curves in Fig. 2.

Figures 1a, b, c, and 2a, b, c, show the respective light, colour and radial velocity observations in the two time intervals, with the 3-harmonics fitted curves. More especially in magnitude V, the residual dispersion σ_{res} of the observed points around the fitted curve is larger in the large time interval case ($t - t_0 = 21$ to 47) than in the other case. An almost negligible part of this increase of dispersion is due to the variation of the pulsation amplitude with time. In reality, the essential cause is the difficulty to obtain completely compatible photometric measurements from different telescopes, photometers and filters.

From the radial velocity curve $V_r(t)$, we can derive several curves which characterize the pulsation cycle: first, the curve of the surface velocity with respect to the stellar center

$$\dot{R}(t) = -\beta(V_r(t) - \bar{V}_r) \quad (2)$$

second, the curve of the radius variation

$$R(t) - R_0 = \int \dot{R}(t)\, dt \quad (3)$$

and third, the curve of the acceleration of the stellar surface $\ddot{R}(t)$, where $\beta = 1.36$ (Burki et al., 1982) is the CORAVEL conversion factor from radial to pulsational velocity, $\bar{V}_r$ is the mean radial velocity and R_0 is the mean stellar radius. These curves are displayed in Fig. 1d.

The variation of the acceleration $\ddot{R}$ during the pulsation cycle is not rapid at any phase. The extreme values of the outwards and inwards acceleration and respectively $+0.83\ \mathrm{ms^{-2}}$ ($\Phi = 0.62$) and $-0.44\ \mathrm{ms^{-2}}$ ($\Phi = 0.09$). In particular, no sharp peak of the

Table 4. The parameters of the differential light, differential colour and radial velocity curves for the measurements in the time interval $t - t_0 = 21$ to 28

	ΔV	Δ(b-y)	V_r
A_0	-0.1861 ± 0.0006	0.1194 ± 0.0006	-14.660 ± 0.028
A_1	0.1014 ± 0.0008	0.0301 ± 0.0009	8.377 ± 0.040
Φ_1[rd]	-1.868 ± 0.008	-1.734 ± 0.030	-2.107 ± 0.005
A_2	0.0149 ± 0.0008	0.0060 ± 0.0009	1.498 ± 0.040
Φ_2[rd]	0.197 ± 0.055	0.137 ± 0.150	0.112 ± 0.027
A_3	0.0033 ± 0.0008	0.0019 ± 0.0009	0.388 ± 0.040
Φ_3[rd]	1.270 ± 0.245	-4.074 ± 0.468	-4.006 ± 0.102
n	27	27	44
σ_{res}	0.0030	0.0033	0.186

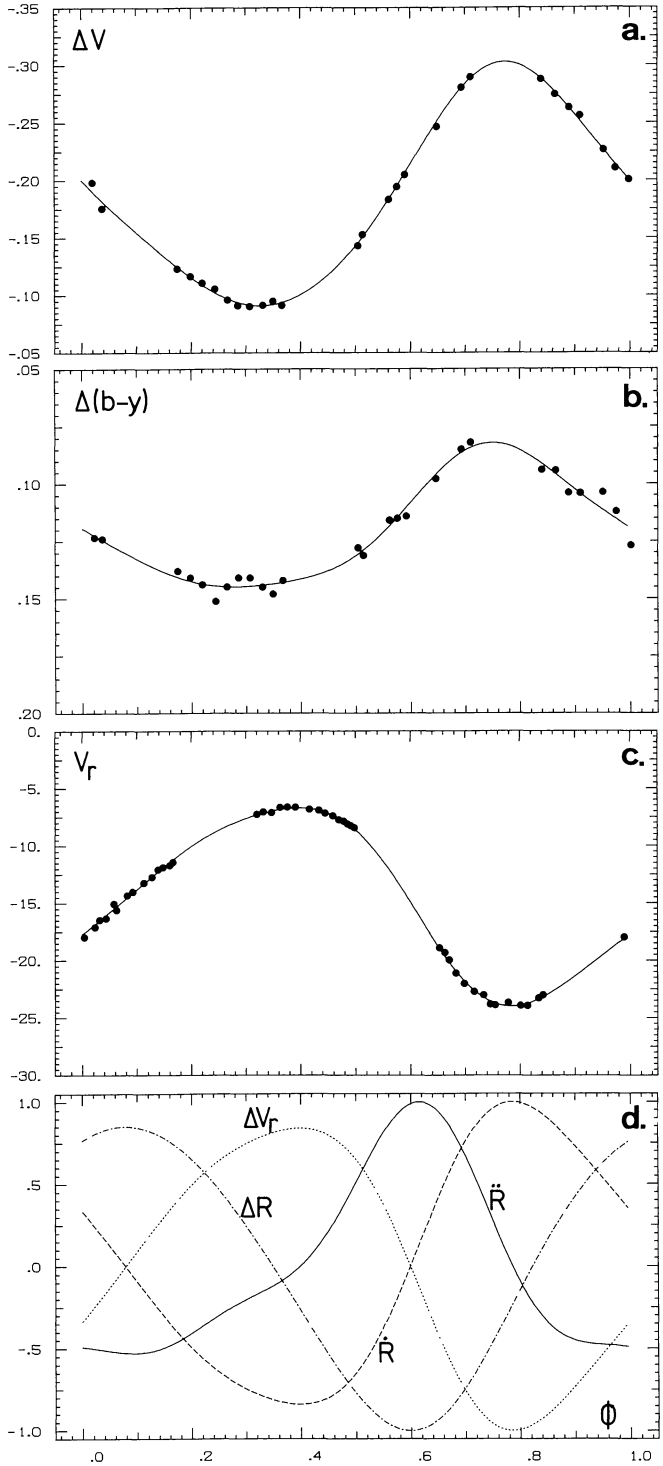

Fig. 1. **a** Light curve in differential magnitude V with the fitted Fourier series for the measurements in the time interval $t - t_0 = 21$ to 28 (data by Schmidt). **b** Idem for the differential $(b - y)$ curve. **c** Idem for the radial velocity curve (data by Burki). **d** Curves of the radial velocity $\Delta V_r = V_r - \bar{V}_r$, of velocity with respect to the stellar center $\dot{R}$, of radius variation ΔR and of acceleration $\ddot{R}$. The value +1.0 of the ordinates corresponds to $+9.44\,\mathrm{km\,s^{-1}}$ for ΔV_r, $+12.8\,\mathrm{km\,s^{-1}}$ for $\dot{R}$, $+0.37\,R_\odot$ for ΔR and $0.83\,\mathrm{km\,s^{-2}}$ for $\ddot{R}$

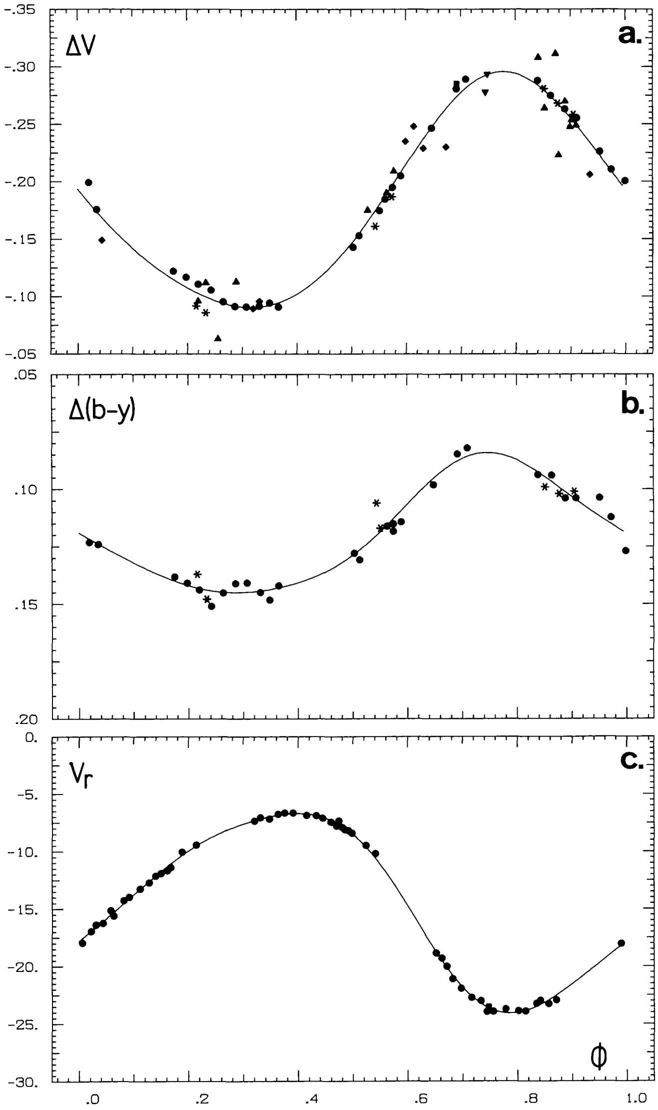

Fig. 2. **a** Light curve in differential magnitude V for the time interval $t - t_0 = 21$ to 47. The type of symbol refers to the author: ● Schmidt, * Fernie, ◆ Arellano Ferro, ▲ Percy, ■ Sasselov, ▼ Szabados. **b** Idem for the differential $(b - y)$ curve. **c** Idem for the radial velocity curve. Type of symbol: ● Burki, ■ Sasselov

acceleration curve is observed at minimum radius, as it occurs in the case of RR Lyrae stars (see Burki and Meylan, 1986a), and the determination of the mean radius R_0 by the Baade-Wesselink method ought not to be too much affected by the dependence of the colour index on another quantity than the effective temperature. For this reason, and also because of the relative small number of observations, the determinations of R_0 in the next section have been performed by considering only the whole pulsation cycle.

3. Determination of the mean radius by the Baade-Wesselink method

3.1. Version of Balona and Stobie (1979b)

From the amplitudes and phases of the first terms in the Fourier series of the light, colour and radial velocity curves, we obtain

Table 5. Same as Table 4 but for the time interval $t - t_0 = 21$ to 47

	ΔV		Δ(b-y)		V_r	
A_0	-0.1825 ± 0.0018		0.1191 ± 0.0007		-14.644 ± 0.030	
A_1	0.1006 ± 0.0025		0.0292 ± 0.0010		8.463 ± 0.042	
Φ_1[rd]	-1.816 ± 0.025		-1.709 ± 0.035		-2.114 ± 0.005	
A_2	0.0124 ± 0.0025		0.0050 ± 0.0010		1.491 ± 0.042	
Φ_2[rd]	-0.009 ± 0.202		0.287 ± 0.204		0.044 ± 0.028	
A_3	0.0012 ± 0.0025		0.0015 ± 0.0010		0.415 ± 0.042	
Φ_3[rd]	0.682 ± 2.009		-4.157 ± 0.691		-4.024 ± 0.102	
σ_{res} n	0.014	61 (Tot)	0.0043	35 (Tot)	0.216	52 (Tot)
	0.005	28 (SC)	0.0035	28 (SC)		
	0.008	7 (FE)	0.0067	7 (FE)		
	0.022	15 (PE)				
	0.021	8 (AF)				
	(0.010)	1 (SA)				
	0.010	2 (SZ)				

the values in Table 6. Remember that the various quantities are the mean radius R_0, the slope A of the surface brightness-$(b-y)$ relation, the phase differences $\psi = \Phi_{b-y} - \Phi_{V_r} + \pi/2$ and $\alpha = \Phi_V - \Phi_{V_r} + \pi/2$, the ratio f of flux to radius variation and the relative radius amplitude ε. The uncertainty on R_0 (and also those on A and f) is very high in the large time interval case. Thus, we retain only the other value for the Balona and Stobie method:

$$R_0 = 50 \pm 15\,R_\odot$$

This value is compatible at the 1σ level with the value $R_0 = 32 \pm 10\,R_\odot$ obtained by Burki et al. (1982) by applying the same method to the measurements made during summer 1980. In addition, according to Balona and Stobie (1979b, 1980), two quantities are important for the identification of the pulsation mode:

$$\psi = 1.94 \pm 0.03\,\text{rad} = 111° \pm 2°$$

$$\Delta\Phi = \Phi_V - \Phi_{b-y} \cong \Phi_V - \Phi_{B-V} = -0.13 \pm 0.04\,\text{rad} = -0.021 \pm 0.006 \text{ in phase}$$

Table 6. The results of the Balona and Stobie (1979) method for the two time intervals $t - t_0$

	$t-t_0$ = 21 to 28	$t-t_0$ = 21 to 47
R_0	50 ± 15 $R_\odot$	63 ± 33
A	3.5 ± 2.1	3.6 ± 3.6
ψ	1.94 ± 0.03 rd.	1.98 ± 0.04
α	1.81 ± 0.01 rd.	1.87 ± 0.03
f	14.5 ± 4.0	17.9 ± 8.4
ε	0.007 ± 0.002	0.005 ± 0.003

Table 7. Values of R_0 in $R_\odot$ from the Burki and Benz (1982) method for the two time intervals $t - t_0$ and for the two cases (parabolic and linear) of the $\log T_{\rm eff} - (b - y)$ relation

	$t-t_0$ = 21 to 28	$t-t_0$ = 21 to 47
Parabolic	47 ± 19 $R_\odot$	47 ± 55 $R_\odot$
Linear	37 ± 14 $R_\odot$	40 ± 43 $R_\odot$

$\Delta\Phi$ must be negative in the case of a radial pulsation and $90° < \psi < 140°$ for the classical cepheids. As we see, the values taken by $\Delta\Phi$ and ψ indicate that HR 7308 is radially pulsating and are not in opposition with the classical cepheid classification.

3.2. Version of Burki and Benz (1982)

In this case, R_0 results from the best fit of ΔR_C (variation of radius from both photometric and radial velocity data) on ΔR_O (integration of the radial velocity curve). The relation between $\log T_{\rm eff}$ and the colour index (in this case: $b - y$) is approximated by a polynomial curve. Table 7 gives the values of R_0 obtained for the linear and quadratic approximation of this relation, in both time intervals. The error on R_0 is derived from the quality of the fit ΔR_C on ΔR_O. It is evaluated by the expression $\varepsilon_{R_0} = 2\,(\partial^2\chi^2/\partial R_0^2)^{-1}$ (see Bevington, 1969). The derivative is calculated from the parabolic curve of S^2 with R_0, where

$$S^2 = \sum_{i=1}^{n} (\Delta R_{C_i} - \Delta R_{O_i})^2/n \quad (4)$$

and from the relation $\chi^2 = S^2 n/\sigma^2_{\rm res}$, where n is the number of photometric data and $\sigma_{\rm res}$ is the residual standard deviation of ΔR_C values around ΔR_O curve. As we see in Table 7, the uncertainties on R_0 are so large in the case $t - t_0 = 20$ to 47 that the mean radius determination is meaningless. In the case of the short time interval, both estimations are in agreement with the value

$$R_0 = 41 \pm 11 R_\odot$$

Recall that Burki et al. (1980) obtained $R_0 = 34 \pm 5\,R_\odot$ by applying a similar method (i.e. the maximum likelihood method of Balona and Stobie (1979a) to the observations of Summer 1980.

3.3. Version of Ivanov (1984)

In this case, the general assumption is that for ΔV and $\Delta(B - V)$ or $\Delta(b - y)$ at the phases of equal radii, i.e. $\Delta R = 0$, the following equation is valid:

$$\Delta V = b\Delta(b - y) \quad (5)$$

where b is a constant, unique for each cepheid. The mean radius R_0 results from an iterative procedure transforming the points of the phases at equal radius on the ΔV, $\Delta(b - y)$ diagram from a loop into a straight line. Thus, Eq. (5) is fulfilled and the coefficient b is evaluated by least-squares solution, Meanwhile, the variation of the radius is obtained by numerical integration of the radial velocity curve with the CORAVEL conversion factor.

For the short time interval $t - t_0 = 21$ to 28 the derived mean radius is:

$$R_0 = 32 \pm 10\,R_\odot$$

In the case $t - t_0 = 21$ to 47 we have:

$$R_0 = 38 \pm 15\,R_\odot$$

4. Analysis of the uvby βRI colours

The average colours of the measurements made by Fernie are:

$b - y = 0.387$ $\quad \beta = 2.703$
$m_1 = 0.252$ $\quad V - R = 0.410$
$c_1 = 0.734$ $\quad V - I = 0.696$

where $(V - R)$ and $(V - I)$ are on the Cousins system. These observations were made differentially with respect to HR 7280 as comparison star, for which the following values were determined from three nights of observation:

$b - y = 0.271 \pm 0.001$ $\quad \beta = 2.712 \pm 0.003$
$m_1 = 0.195 \pm 0.005$ $\quad V - R = 0.298 \pm 0.003$
$c_1 = 0.487 \pm 0.009$ $\quad V - I = 0.474 \pm 0.004$

The value $(b-y)=0.387$ is equivalent to $(B-V)=0.64$ (Cousins and Caldwell, 1985), which agrees with the value found previously (Fernie, 1982). This is an important confirmation since this value of $(B - V)$ places the star redward of the usual instability strip. When this $(B - V)$ and the value of $(V - I)$ are applied according to the precepts of Dean et al. (1978) to find the colour excess, the result is $E(B - V) = 0.04$, which agrees well with the values of 0.03 and 0.04 found by van Genderen (1981) and Fernie (1982) respectively. Adopting $E(B - V) = 0.04$, one obtains the following intrinsic colours:

$b - y = 0.36$ $\quad \beta = 2.703$
$m_1 = 0.26$ $\quad V - R = 0.39$
$c_1 = 0.73$ $\quad V - I = 0.65$

These values of $(b - y)$ and m_1 are very similar to those for classical cepheids generally (Feltz and McNamara, 1980), and definitely indicate [Fe/H] = 0 or even >0 for HR 7308. Likewise, the combination of $(b - y)$ and c_1 is entirely normal for a cepheid, suggesting $\log g \simeq 1.8$ from the calibration by the theoretical stellar atmospheres of Kurucz (1979). (See Figure 3 of Fernie and Garrison, 1984, for an example of such an application).

The value of β, though, is larger than that of any other among 41 cepheids measured by Feltz and McNamara. However, their data show that cepheids with periods less than about 10 days obey a relation

$$\langle\beta\rangle = 2.685 - 0.053 \log P$$
$$\pm 0.008 \quad 0.010$$

with a standard deviation of 0.011 mag. (Longer period cepheids show $\langle\beta\rangle$ values essentially uncorrelated with $\log P$). Thus the relatively large value of $\langle\beta\rangle$ for HR 7308 is at least mainly accounted for by its very short period. The above formula predicts $\langle\beta\rangle = 2.676$ for HR 7308, which is about a 2σ departure from

the measured value. Given the potential for zero-point errors between the two sets of photometry, this is not likely significant, and we conclude there is no good evidence for any abnormality in the strength of $H\beta$ compared to other cepheids.

Nevertheless, there is a conflict between the values of β and $(b-y)_0$ if both are taken as temperature indicators. As noted above, β is normal or perhaps higher than expected for the period, and the effective temperature is therefore average or above average. But $(b-y)_0$ is decidedly redder than expected for the period, suggesting that T_e is definitely below average. An excess of about $E(B-V)=0.25$ would be needed to reconcile the difference, and this is definitely not supported by the other colour data.

This impinges on the question of whether or not the star is an overtone pulsator. A colour too red for the observed period might be interpreted as appropriate to the longer fundamental period, implying that the star *is* an overtone pulsator. But on the other hand, β fits the observed period, suggesting that the latter is the fundamental period. This conflict remains unresolved at present.

5. Analysis of the Fourier coefficients

Using the values given in Tables 4 and 5, we may easily compute the Fourier phase differences ϕ_{21}(light) and ϕ_{21}(velocity) and the first-order phase lag, $(\Delta\phi)_1$. We obtain the following values for the data of Table 4 and, given in paranthesis, Table 5: ϕ_{21}(light) = 3.93(3.62); ϕ_{21}(velocity) = 5.90(5.84); $(\Delta\phi)_1 = -0.24(-0.30)$. The agreement between the two data-sets is very good despite the considerable scatter displayed in Fig. 2a for the large-time-interval observations. Because of this scatter we shall use, in what follows, the numbers from Table 4 rather than those from Table 5.

Comparing the values of ϕ_{21}(light), ϕ_{21}(velocity) and $(\Delta\phi)_1$ for HR 7308 with values for the short-period classical cepheids as given by Simon and Lee (1981) (light), Simon and Teays (1983) (velocity) and Simon (1984) (phase lag), one sees that HR 7308 falls very comfortably among the fundamental mode pulsators. Thus, based strictly upon the Fourier decomposition data, there is no reason to consider this star an overtone.

Simon (1985) constructed a linear non-adiabatic pulsation model for HR 7308 consistent with second-overtone pulsation. The parameters for this model were $M=5M_\odot$, $L=1000\,L_\odot$, $T_e=6110$ K. For the present work we have calculated a fundamental mode model with the parameters $M=3.82\,M_\odot$, $L=398\,L_\odot$, $T_e=5850$ K given by Arellano Ferro (1984). The three lowest modes of this model have periods and growth rates (P,η) as follows: (1.56, 2.6E-3), (1.18, 1.1E-2) and (0.95, 2.0E-2). Although the fundamental growth rate is rather small, the model is so cool that it may lie beyond the overtone red edges. Certainly, it seems that overtone and fundamental mode pulsation are both viable based upon the linear models we have described.

6. Discussion

The *uvby* β and *VRI* photometric analysis confirms that HR 7380 has a solar chemical composition and suggests the gravity value $\log g=1.8$ (Sect. 4). In addition, the galactic component of the velocity and the distance to the galactic plane have relatively small values (see Burki and Mayor, 1980b). So, *one suspects the star to be a Population I cepheid.*

Table 8. Value of the mass in $M_\odot$ for various values of the gravity $\log g$ and of the mean radius R_0 in $R_\odot$

mean radius $R_\odot$	log g 1.6	1.8	2.0
20	0.6	0.9	1.5
25	0.9	1.4	2.3
30	1.3	2.1	3.3
35	1.8	2.8	4.5
40	2.3	3.7	5.9
45	3.0	4.7	7.4

The three versions of the Baade-Wesselink method we used are in favour of a large value of the mean radius: $R_0>30\,R_\odot$. In Table 8 are given the values of the mass corresponding to $\log g=1.8\pm0.2$ and to six values of R_0 (from 20 to $45\,R_\odot$). For example, a mass of $2.8\,M_\odot$ corresponds to the values $R=35\,R_\odot$ and $\log g=1.8$. Under the hypothesis that HR 7308 is a Population I cepheid, *the above values, together with the period, require pulsation in a high overtone, at least the second.*

However, we have to consider that these two main conclusions (i.e. Population I and high overtone) are no longer undubitably established and the following comments are to be made:

1) Both, the Baade-Wesselink radius and the surface gravity are difficult to determine accurately. On the other hand, the surface gravities of the linear models of Sect. 5 are $\log g=2.24$ and 2.44 for the second overtone and fundamental mode, respectively. Clearly, then, much caution must be exercised before one rules out fundamental mode (or, for that matter, first overtone) pulsation on the basis of Table 8.

2) The values of the Fourier coefficients of the light and radial velocity curves are in agreement with a pulsation in the fundamental mode (see Sect. 5). However, it must be emphasized that a high overtone pulsation cannot be excluded only on the basis of the analysis of the Fourier coefficient since the normal values of the various phase differences ϕ_{21}(light), ϕ_{21}(velocity), $(\Delta\phi)_1$ are unknown for the second (and higher) overtone.

3) The period of HR 7308 is right for a Population II cepheid, and since a number of these cepheids have locations in the galactic disk, low space velocities and high metal contents, the possibility still exists that HR 7308 is a low mass star with $M\sim0.6\,M_\odot$. However, the radius-period relation for Population II cepheids (see Burki and Meylan, 1986b) predicts a radius of about $10\,R_\odot$ for a period of 1^d5. Then, the classification of HR 7308 as a Population II cepheid would imply that the various Baade-Wesselink values of the radius yet obtained for this star are overestimated by a factor 2 to 4.

In conclusion, a classical cepheid pulsating in the second (or higher) overtone is the most probable explanation for the variability of HR 7308, but the other possibilities (i.e. fundamental

mode or first overtone, Population II cepheid) cannot be yet definitively ruled out. Other observational and theoretical studies are required in order to understand the strange behaviour of this unique Cepheid.

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