A STUDY OF THE VARIABILITY OF THE DELTA SCUTI STARS

V: *Photoelectric Photometry of the Bright Star HR 2557*

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Abstract. More than 1700 photmetric V observations of the Delta Scuti HR 2557, obtained at the Merate Observatory during the two periods: 1979–80 and 1981, are analyzed. In spite of the fact that the sets of frequencies for the two periods are similar, the interpretation of these oscillations is far to be satisfactory. The lowest frequencies can be reasonably interpreted as corresponding to the lowest radial modes. Unfortunately, nothing can be said about the highest frequencies.

1. Introduction

HR 2557 has been classified as a F0 δ Del star by Cowley and Crawford (1971) on the basis of some 80 Å/mm spectra. Afterwards Morgan and Abt (1972) regarded this object as a A9III standard star and Cowley (1976) confirmed this classification. Kurtz (1976) performed a fine abundance analysis, but his results are not conclusive. Recently Jaschek (1982) declined to recognize the δ-Del nature of the star.

As regards as the photometric variability, Kurtz (1977) observed HR 2557 during seven nights in 1975–76, but the analysis of the data was inconclusive because of the poorly defined peaks in the power spectrum. The analysis performed on a night-by-night basis pointed out a period of about four hours, but the author concluded that "...the very low amplitude of the light variations coupled with at least one period of the order of four hours makes an accurate determination of the periodicities present in the star impossible with the present data...".

In the framework of the photometric photometry on Delta Scuti stars, started some years ago at the Merate Observatory, we observed HR 2557 in the V colour for seventeen night distributed during two observational seasons: 1979–80 (seven nights) and 1981 (ten nights) (for instrumental equipment and the reduction procedure, see Bossi *et al.*, 1977). HR 2532 (spectral type A5) was the comparison star and HR 2585 (spectral type A2V) the check star. In all we collected more than 1700 observations grouped in 327 normal points (see Table I, where we also report the observational times and the standard errors σ).

2. Analysis of the Data and Discussion

The 1979–80 and 1981 observations have been analyzed separately with a method similar to that proposed by Vaníček (1971), which has been used by us in other works

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TABLE I

Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ
44207.433	.087	.002	44211.460	.082	.001	44214.475	.096	.003
.450	.094	.002	.465	.081	.001	.495	.085	.002
.454	.087	.002	.471	.085	.002	.503	.085	.004
.458	.090	.002	.492	.072	.001	.508	.088	.002
.464	.086	.001	.498	.073	.003	.527	.091	.003
.482	.089	.001	.503	.074	.002	.544	.094	.002
.486	.088	.002	.507	.072	.003	.564	.096	.003
.493	.089	.002	.525	.080	.002	.571	.092	.002
.518	.080	.001	.530	.080	.001	.577	.090	.002
.522	.081	.002	.534	.077	.002	.582	.087	.002
.526	.079	.002	.538	.085	.002	.605	.083	.002
.530	.081	.002	.551	.078	.001	.612	.081	.002
.549	.083	.001	.556	.081	.002	.616	.081	.002
.554	.087	.002	.562	.080	.003	.620	.084	.001
.560	.085	.003	.566	.076	.001	.623	.086	.004
.582	.082	.002	.582	.082	.002	.652	.091	.002
.590	.080	.002	.587	.081	.001	.657	.091	.002
.609	.074	.002	.593	.093	.004	.661	.093	.002
.617	.072	.002	.596	.088	.004	.669	.096	.003
.629	.077	.001	.612	.086	.001	.690	.096	.003
.636	.071	.003	.617	.089	.001	.705	.096	.002
.652	.091	.001	.623	.095	.001	.711	.089	.001
.655	.091	.001	.639	.086	.003	.714	.093	.002
.659	.091	.002	.644	.083	.002	44241.443	.082	.003
.677	.094	.001	.648	.084	.002	.447	.083	.002
.685	.094	.002	.661	.088	.001	.454	.082	.003
.693	.097	.002	.666	.085	.001	.461	.079	.002
.698	.094	.002	.670	.083	.001	.466	.081	.001
.701	.095	.001	.674	.085	.003	.471	.070	.007
.710	.081	.002	.690	.086	.001	.501	.072	.003
44208.432	.086	.002	.694	.095	.001	.508	.070	.012
.435	.087	.001	.698	.096	.002	.514	.078	.002
.439	.091	.002	44212.415	.101	.003	.534	.077	.002
.445	.092	.002	.440	.101	.001	.540	.078	.002
.461	.095	.002	.444	.101	.003	.544	.082	.001
.466	.079	.002	.449	.105	.002	.549	.078	.005
.471	.081	.001	.483	.090	.008	.555	.075	.002
.477	.085	.002	.488	.087	.003	.577	.056	.006
.498	.085	.002	.493	.090	.003	.584	.060	.021
.504	.088	.001	.497	.081	.002	.589	.071	.004
.508	.087	.001	.500	.082	.003	.597	.074	.004
.512	.083	.002	.505	.084	.002	.608	.076	.004
.517	.087	.001	.508	.081	.001	44620.300	.085	.002
.535	.081	.002	.525	.083	.002	.308	.085	.002
.539	.078	.003	.528	.081	.002	.317	.085	.003
44210.473	.081	.003	.532	.082	.003	.349	.077	.001
.478	.088	.003	.537	.087	.003	.358	.072	.002
.482	.087	.003	.541	.086	.001	.377	.069	.002
.488	.090	.001	.545	.084	.002	.382	.070	.002
.576	.084	.003	.567	.087	.001	.468	.090	.001
.580	.084	.003	.570	.087	.002	.473	.085	.002
.583	.088	.001	.574	.085	.001	.478	.084	.002
.586	.082	.001	.581	.082	.001	.522	.081	.001
.591	.082	.002	.600	.080	.001	.530	.075	.002
.609	.081	.003	.607	.076	.001	.569	.074	.001
.614	.087	.003	.613	.079	.001	.575	.070	.002
.617	.080	.003	.617	.075	.001	.599	.071	.002
.623	.088	.003	.639	.080	.001	.604	.071	.001
.638	.085	.002	.650	.082	.001	.614	.080	.002
.649	.096	.005	.658	.081	.002	.620	.078	.002
44211.396	.102	.002	.675	.083	.001	.649	.088	.002
.402	.098	.001	.685	.081	.001	.664	.084	.002
.407	.102	.002	.690	.084	.002	44621.285	.089	.002
.423	.092	.002	44214.417	.091	.002	.293	.082	.002
.428	.104	.002	.426	.092	.002	.298	.087	.001
.433	.092	.002	.458	.093	.002	44622.234	.103	.003
.439	.093	.003	.462	.092	.002	.286	.081	.003
.455	.088	.002	.469	.090	.002	.309	.081	.003

Table I (continued)

Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ	Hel. J.D. 2400000+	ΔV	σ
44622.315	.083	.003	44626.589	.088	.003	44628.414	.081	.001
44623.324	.085	.003	.595	.089	.003	.424	.083	.002
.330	.084	.002	.626	.085	.002	.446	.078	.001
.335	.083	.002	.633	.090	.002	.452	.082	.001
.353	.079	.002	44627.256	.093	.005	.482	.083	.002
.359	.080	.002	.263	.092	.003	.486	.084	.001
.365	.074	.002	.270	.088	.002	.491	.087	.001
.381	.077	.001	.292	.090	.003	.506	.084	.001
.387	.077	.002	.299	.093	.003	.512	.084	.001
.392	.073	.002	.304	.092	.002	.519	.079	.001
.408	.080	.002	.310	.094	.001	.525	.087	.002
.413	.077	.004	.327	.092	.002	.543	.086	.002
.419	.085	.001	.336	.093	.001	.548	.086	.002
.440	.078	.002	.434	.087	.002	.553	.090	.001
.446	.079	.003	.439	.089	.002	.559	.093	.001
.452	.080	.001	.458	.089	.003	.579	.090	.001
.467	.084	.003	.463	.086	.003	.586	.091	.001
.480	.088	.001	.482	.081	.001	.609	.091	.001
.485	.096	.002	.486	.091	.002	44629.252	.086	.002
44626.255	.088	.003	.490	.083	.004	.279	.070	.001
.260	.090	.005	.544	.091	.004	.292	.076	.003
.376	.082	.001	.549	.083	.001	44630.263	.070	.002
.379	.088	.004	.567	.081	.003	.283	.070	.002
.383	.091	.001	.571	.084	.003	.293	.074	.002
.386	.089	.002	.584	.083	.003	.384	.096	.002
.396	.083	.002	.588	.078	.002	.445	.077	.002
.399	.083	.002	.608	.090	.002	.466	.076	.001
.402	.079	.002	.613	.085	.003	.493	.082	.002
.420	.070	.002	.628	.092	.005	.502	.079	.003
.426	.072	.001	.633	.092	.005	.523	.084	.002
.432	.072	.002	.652	.088	.006	.532	.080	.003
.449	.078	.002	.657	.092	.005	44631.265	.084	.008
.455	.080	.002	44628.331	.087	.002	.299	.081	.005
.462	.084	.004	.339	.084	.003	.321	.089	.003
.482	.090	.002	.346	.086	.002	.416	.072	.003
.498	.085	.002	.350	.085	.001	.439	.085	.004
.515	.076	.002	.376	.088	.002	.450	.089	.003
.542	.082	.002	.381	.082	.001	.473	.089	.002
.550	.080	.002	.386	.081	.001	.483	.088	.003
.558	.088	.002	.390	.087	.001	.523	.077	.003
.582	.084	.003	.395	.082	.002	.534	.082	.003

(see Bossi *et al.*, 1977). For each trial frequency, a least squares solution is made simultaneously for the amplitudes of all known constituents of the data and the amplitude and phase of the sine wave with the trial frequency. Table II shows the frequencies corresponding to the two observational groups, the related amplitudes and the initial and final residuals.

We must say at once that the attempt to interpret all the frequencies in the framework of the theoretical knowledge about pulsations of Delta Scuti stars, was not entirely successful. What we can say, regarding the present state of the theory and the amount of the observational data, can be summarized as follows:

(1) The frequency $f_0 = 1.76c/d$ in Group 1 (probably represented in Group 2 by its 1 day^{-1} alias at $0.80c/d$) could be related to the fundamental radial mode. In fact, from the Stromgren indices of HR 2557 (Hauck and Mermilliod, 1980), we can calculate $T_{\rm eff}$, $\log g$ and $M_{\rm bol}$, using respectively the formula 3 in Petersen and Jorgensen (1972) and Breger's (1974) calibration and assuming $BC = -0\overset{m}{.}08$ (Table III). If we introduce these

TABLE II

	Frequencies (c/d)	Amplitudes
Group 1 (1979–80)	1.76 ± 0.04	$0^m.0031$
	1.99 ± 0.04	$0^m.0106$
	2.41 ± 0.04	$0^m.0035$
	6.13 ± 0.04	$0^m.0030$
	9.71 ± 0.04	$0^m.0036$
Initial residual:	$0^m.0066$	
Final residual:	$0^m.0033$	
Group 2 (1981)	0.80 ± 0.02	$0^m.0020$
	3.94 ± 0.02	$0^m.0042$
	4.74 ± 0.02	$0^m.0030$
	6.15 ± 0.02	$0^m.0035$
	9.65 ± 0.02	$0^m.0030$
Initial residual:	$0^m.0065$	
Final residual:	$0^m.0036$	

TABLE III

$b - y = 0.221$	$\delta c_1 = 0.363$
$m_1 = 0.141$	$\delta m_1 = 0.040$
$c_1 = 1.023$	$T_{\text{eff}} = 7300$
$\beta = 2.741$	$\log g = 3.0$
	$M_{\text{bol}} = 0^m.0$

quantities into the formula 5 of Petersen and Jorgensen (1972), we obtain $Q = 0^d.046$: this value is not very far from the theoretical one for the fundamental radial mode (Petersen, 1975), taking into account the errors related to the photometric determination of the physical parameters. On the other hand, from *P–L–C* relation related to the fundamental radial mode (Gupta, 1978), we obtain $M_{\text{bol}} = -0^m.5$: because we estimate that the external error in M_{bol} could be as large as $\pm 0^m.5$, the agreement with the luminosity calculated by means of $ubvy\beta$ photometry, is satisfactory.

(2) The frequency $f_1 = 2.41 c/d$ present in Group 1 (in Group 2 it seems that there is its first harmonic of $4.74 c/d$) could be the first radial overtone. In fact the relative Q-value is equal to $0^d.034$, so that $Q_1/Q_0 = f_0/f_1 = 0.73$: this ratio agrees well with that theoretically estimated for the fundamental mode and the first overtone.

(3) The frequencies $1.99 c/d$ and $3.94 c/d$ (included respectively in Group 1 and Group 2) could be the 1 day^{-1} and 1 day aliases of $f_2 \simeq 3 c/d$, which corresponds to the second radial overtone. Indeed the ratio f_0/f_2 agrees very well with the theoretical value.

(4) In this paper we could not explain the two frequencies near to $6.1 c/d$ and $9.7 c/d$, although they are present in both groups of data and are statistically significant. These waves are not related neither to high radial modes nor to nonradial modes: in fact their ratios with f_0, f_1, and f_2 are different at all from the theoretical ones.

The remark that $6.1 - 2.4 \simeq 9.7 - 6.1 = 3.7 = \Delta f$, could support the hypothesis that the pulsations corresponding to $2.4 c/d$, $6.1 c/d$ and $9.7 c/d$ are different m-modes associated with a single non-radial pulsation. This suggestion, that should upset the radial mode interpretation of f_1, disagrees with the previous conclusions about the ratios of the frequencies, and, on the other hand, is ruled out by the following considerations. Using the relation (Ledoux, 1951): $V_{\text{rot}} = (2\pi/0.9)(\Delta f/\Delta m)R$ with $\Delta f = 3.7c/d$ and $R = 4R_\odot$ (Allen, 1973), we obtain $V_{\text{rot}} = 833/\Delta m$ km s^{-1}. So, to obtain a satisfactory agreement with the projected rotational velocity of HR 2557 (equal to 30 km s^{-1}, Bernacca, 1973), we should adopt a Δm value too large.

Our conclusion is that the identification of the pulsational modes associated with these frequencies is not reached with the present data.

(5) If we take into account the presence of the aliases, the set of frequencies found in Group 1, although not easy to interpret, is not substantially changed from 1979–80 to 1981, in Group 2. So it seems that HR 2557 supports the hypothesis about the stability of the pulsational modes over long time.

3. Conclusions

Delta Scuti star HR 2557 shows two similar sets of frequencies during the two observational seasons in the years 1979–80 and 1981. The interpretation of these oscillations is far to be satisfactory. The frequencies of $1.76c/d$ and $2.41c/d$ can be reasonably interpreted as corresponding to the fundamental mode and the first overtone; those at $1.99c/d$ and $3.94c/d$ could be the 1 day^{-1} and 1 day aliases of the second radial overtone. Nothing, for the present, can be said about the highest frequencies of $6.1c/d$ and $9.7c/d$.

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