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EC 20058 − 5234, a low-amplitude pulsating DB white dwarf

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ABSTRACT

EC 20058 − 5234 is the eighth pulsating helium white dwarf to be discovered. At least eight periodicities have been observed in about 52 h of high-speed photometry, the most prominent being at 281 and 257 s. Many of the periodicities appear to be permanent features of the light curve, but the amplitudes vary: the strongest mode has been observed at amplitudes between 6 and 13 mmag. The star is exceptional in the group of DBVs because of both its short periods and its low amplitudes.

Key words: stars: individual: EC 20058 − 5234 – stars: oscillations – white dwarfs.

1 INTRODUCTION

The Edinburgh–Cape Faint Blue Object survey (Stobie et al. 1992) has led to the discovery of many previously unknown white dwarf stars. Amongst these, about 10 per cent are helium-rich DB stars. In this paper, the presence of low-amplitude, high-frequency oscillations in the newly discovered DB white dwarf EC 20058 − 5234 is reported. The coordinates of the star are $\alpha(2000)=20^h09^m40^s$, $\delta(2000)=-52°25'22''$ (but also see the finding charts given below). This is the eighth DBV star found to date (see Bradley 1993 for a reference list), and it is of particular interest because of its extreme properties compared with other stars of this type. Furthermore, at a magnitude of $V=15.6$, it is the second brightest known DBV star.

Recently, there has been a quantum jump in understanding of the pulsation properties of the DAV (also known as ZZ Ceti) stars with the realization that the oscillation modes all appear to belong to one underlying structure (Clemens 1993). It is of interest to see whether a similar unification of the pulsation periods of the DBVs is possible. The best-studied DBV by far is GD 358, having been the subject of a Whole Earth Telescope campaign (Winget et al. 1994). Table 1 contains the mode identification of the most prominent periodicities observed in this star (Winget et al. 1994; Bradley & Winget 1994). For comparison, the periods seen in all other previously known DBVs are also tabulated alongside the closest match to a period in GD 358 (we thank T. Watson and collaborators for drawing our attention to the similarities). The agreement in the periodicities observed in the other DBVs with those found in GD 358 appears to be reasonable, where there is an overlap. Below, we consider the pulsation behaviour of EC 20058 − 5234 in relation to the information in Table 1.

The acquisition of our observations is briefly described (Section 2), before proceeding to an analysis of the periodicities in the data (Section 3). In Section 4 the results are discussed and compared with those for other DBV stars. A concluding remark follows in Section 5.

2 THE OBSERVATIONS

The selection of candidate objects for the Edinburgh–Cape survey has been described by Stobie et al. (1992) and will not be detailed here. Classification of EC 20058 − 5234 as a DB white dwarf is of course based on spectroscopic evidence. Fig. 1 shows the sum of two spectra obtained in the Edinburgh–Cape survey using the 1.9-m telescope at the Sutherland site of the SAAO, and a Reticon photon-counting system. These two spectra were flat-field corrected, wavelength-calibrated, sky-subtracted, flux-calibrated, added together and slightly smoothed. Only broad He I lines are visible. The spectrograph is not suitable for spectrophotometry, so that absolute fluxes cannot be determined: the flux must be regarded as relative only.

Photoelectric photometry of the star gives $V=14.93$, $B-V=+0.32$ and $U-B=-0.74$. The colour indices, particularly $B-V$, are anomalously red for a DB white dwarf star. The reason for this can be seen in Fig. 2(b), which shows a chart based on a 10-s white light CCD exposure of a 1.26×1.6 arcmin^2 field containing the star. Two other stars are close to the DBV, separated from it by 2 and 4 arcsec, respectively. As a result, aperture photometry of the DBV star with a photoelectric photometer will be contaminated by the light from these companions. In order to obtain the true brightness and colours of the DBV, CCD frames in *UBVRI* were acquired and yielded the following result: the companion nearest to the DBV has $V=15.74$, $V-R=0.32$ and

Table 1. Radial overtone number for the $\ell=1$ modes in GD 358 according to Winget et al. (1994), and the periods (in seconds) observed in all previously known DBV stars. An asterisk indicates a mean value of periods observed on different nights that lie within 11 s of the mean value. The maximum amplitude (in mmag) observed for each mode is given in brackets.

Mode (k)	GD358	PG1654 +160	PG1115 +158	PG1351 +489	PG1456 +103	KUV05134 +2604	CBS114
			~ 2500 (13)				
			~ 1000 (19)				
		851 (22)			849 (8)	861 (14)	
					785* (20)		
17	771 (15)						
16	734 (3)						
15	701 (19)					704* (41)	
14	658 (8)				664* (21)		650 (39)
13	618 (6)					603 (12)	
12	577 (1)	578 (27)				579 (9)	
11	542 (1)						
10	502 (1)			490 (74)			
9	464 (5)						
8	423 (5)				422* (9)		
7?						391 (12)	
6?						354* (19)	

Sources: GD 358: Winget et al. (1994); PG 1654+160: Winget et al. (1984); PG 1115+158, PG 1351+481: Winget, Nather & Hill (1987); PG 1456+103: Grauer et al. (1988); KUV05134+2604: Grauer et al. (1989); CBS 114: Winget & Claver (1989).

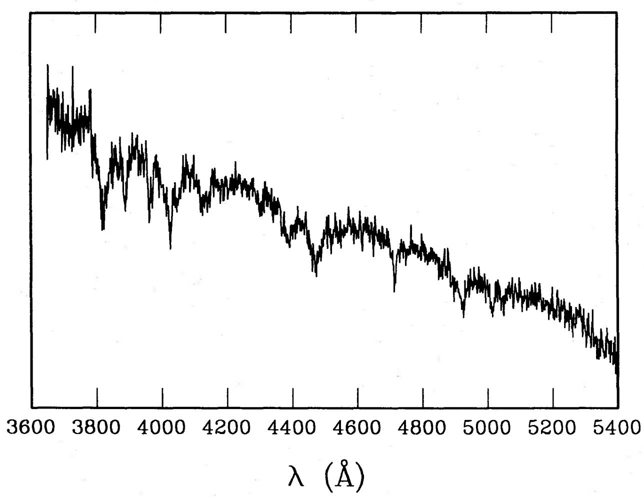

Figure 1. The Edinburgh–Cape Faint Blue Object survey spectrum of EC 20058 − 5234. Only He I lines are visible.

$V-I=0.67$ and the other companion (at 4-arcsec separation) has $V=17.83$, $V-R=1.41$ and $V-I=2.93$. Neither of the companions yielded measurable flux in the U and B bands. The DBV star was found to have $V=15.58$, $B-V=-0.04$, $U-B=-0.71$, $V-R=-0.24$ and $V-I=-0.37$. The uncertainty on these values could be as large as several hundredths of a magnitude because of the poor seeing conditions under which the CCD observations were obtained. A larger area finding chart is given in Fig. 2(a).

About 52 h of high-speed photometry of EC 20058−5234 were obtained; the observing log is given in Table 2. Both aperture photometry (with photomultipliers) and high-speed CCD photometry (O'Donoghue et al., in preparation) were used to collect the data. No filter was placed in the light beam. As the photomultiplier tubes used were blue-sensitive, their effective wavelength response is close to that of a B filter but with a much broader bandpass. In two runs, a Wright Instruments CCD was used as the detector. Although this instrument has considerable blue response, it has greatest sensitivity in the V band, so these data should be viewed as being in a 'broad V band'. The CCD data were also obtained with 10-s time resolution and no 'dead time' (due to the operation of the CCD in frame transfer mode). A typical light curve is shown in Fig. 3. Low-amplitude oscillations with a period of ~4 min are discernible in the light curve. The reality and coherence of these oscillations are confirmed by Fig. 4, which shows the periodogram of the longest run, a portion of which appears in Fig. 3.

3 PERIODICITIES IN THE EC 20058 − 5234 LIGHT CURVES

Fig. 5 shows the periodograms of all the individual runs. The following period-extraction strategy was followed: for each run, the interval 2.8–12 mHz was sampled at 4-μHz intervals, and all peaks above 1.6 mmag were listed. Typically, about 30 frequencies per run were identified in this way. The lists for the various runs were then compared, and frequencies common to several runs were noted. These are given in Table 3. We also noted the presence of potentially significant peaks which occurred in only one or two runs, or were close to and barely resolved from the two largest peaks. We adopt a conservative approach and do not include these in Table 3

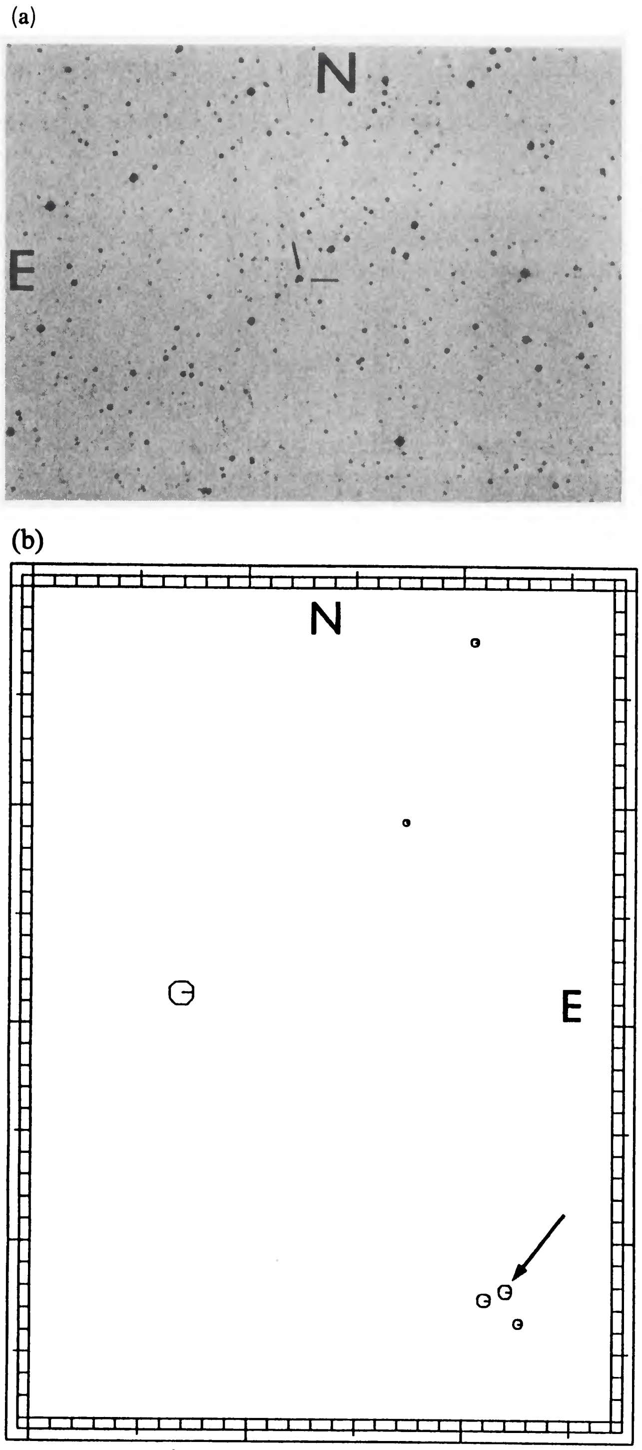

Figure 2. (a) An ESO Red Survey map of the sky, centred on the position of EC 20058 – 5234. The field size is approximately 14 × 11 arcmin^2. (b) A detailed finding chart based on a white light CCD exposure of a 1.25 × 1.6 arcmin^2 field containing EC 20058 – 5234 (indicated by the arrow). The bright star near the centre of the field has a V magnitude of 13.9.

but note that further frequencies may be discovered from multisite observing campaigns. The detection of frequencies below about 2.8 mHz requires special treatment and will be discussed below.

Note that the amplitudes of the peaks from the photo-

Table 2. Log of high-speed photometric observations of EC 20058 – 5234. All these observations consisted of continuous runs of 10-s integrations in white light. StAP is the SAAO St Andrews photometer; UCTP is the University of Cape Town Photometer; WICC is the University of Cape Town's Wright Instruments CCD Camera.

Starting Time HJD2440000+	Telescope	Instrument	Run Length (Hours)
9486.594	1.0m	StAP	1.73
9489.504	1.0m	StAP	3.96
9504.468	1.0m	StAP	5.05
9505.448	1.0m	StAP	5.61
9515.516	0.75m	UCTP	3.94
9540.383	1.0m	StAP	6.78
9544.368	1.0m	StAP	4.09
9545.307	1.0m	StAP	8.73
9562.404	1.0m	WICC	2.65
9563.357	1.0m	WICC	5.32
9629.247	0.75m	UCTP	3.78

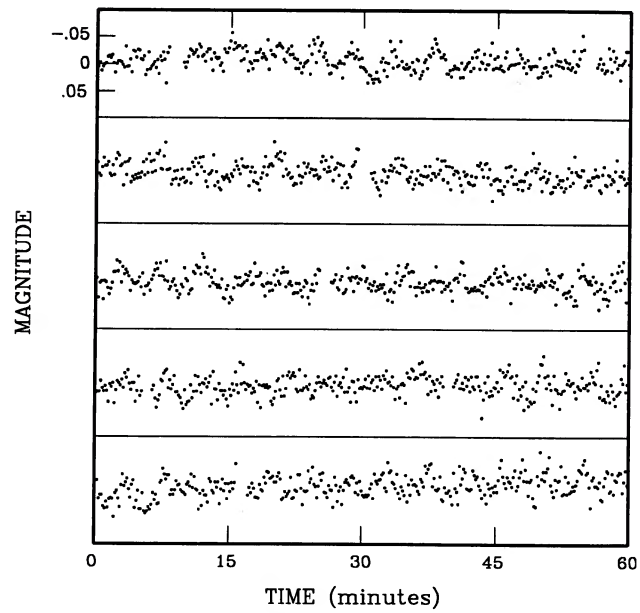

Figure 3. A 5-h portion of the light curve of EC 20058 – 5234, obtained during the run on JD 244 9545. The vertical scale of each of the panels is 0.2 mag. The data have been pre-whitened by subtraction of a parabolic trend fitted to the entire 8.7-h run.

electric photometry listed in Table 3 (and appearing in Figs 3 and 4) are smaller than the true amplitudes because the two companion stars were included in the aperture. Given the response of the blue-sensitive photomultiplier, the photoelectric observations may be thought of as comprising a weighted sum of radiation in the U, B and V bands. The companion stars make a negligible contribution to the U filter, while only the brighter companion adds substantially in B. Using crude estimates of the $B-V$ colours of the companions (based on their colours in the red wavebands), we find that the photoelectrically determined amplitudes in Table 3 should be scaled by a factor ~1.4. We emphasize that we have not performed this scaling. The magnitudes

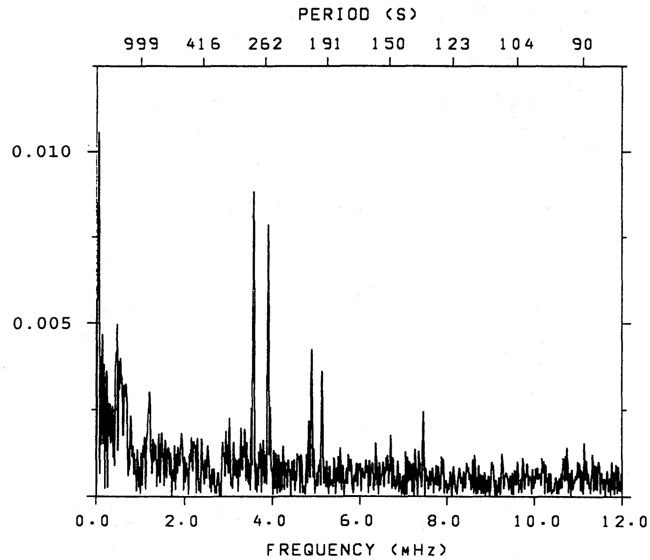

Figure 4. The amplitude spectrum of the 8.7-h run on JD 244 9545. The vertical scale is measured in magnitude units.

determined from the CCD observations were found by profile fitting, and hence do not suffer the problem of dilution by the companions' light. We speculate that the amplitude of the variations is independent of wavelength in the sensitivity range of the instruments used, as the wavelengths of interest lie on the Rayleigh–Jeans tail of the energy distribution. If this assumption is valid, the amplitudes from the CCD photometry can be compared directly with those from the photoelectric photometry (after the latter have been scaled by ~1.4).

A glance at Fig. 5 shows that the low-frequency ends of the periodograms are severely contaminated by the effects of slow atmospheric extinction changes. In order to decide whether there are any low-frequency (i.e. below 2.8 mHz) oscillations in EC 20058 − 5234, it was therefore necessary to resort to slightly more elaborate procedures. First, the data were detrended by differencing, i.e. subtraction of successive data points; this is known to be an excellent technique for removing trends (e.g. Box & Jenkins 1976). The periodogram of the differenced data then shows greatly reduced power at very low frequencies. Finally, the distorting influence of the differencing procedure on the periodogram frequency range of interest can be removed by dividing by the so-called transfer function,

$$T(\nu)=4\sin^2\pi\nu$$

(see e.g. Lombard & Koen 1993).

The periodograms obtained in this way typically have about 40 peaks in the interval 0.5 to 3 mHz. This was reduced by inspecting amplitude spectrum plots and removing what were considered to be random fluctuations, leaving from 12 to 20 peaks for the 10 long runs involved in the exercise. The lists of peak frequencies for the various runs were then compared, and coincidences selected according to the criterion that a given peak be present in at least one-half of the runs, within 0.04 mHz of one another. The results, which should be viewed with suitable caution, are shown in Table 4.

Inspection of the periodogram plots and the various tables immediately makes apparent a number of facts that contrast with the results for the other DBVs in Table 1.

(i) The maximum amplitude of all the modes observed in EC 20058 − 5234 was 12.7 mmag, which after scaling is about 18 mmag. This is small compared with the maximum mode amplitudes seen in most other DBVs, suggesting that this star is a low-amplitude pulsator. This conclusion is reinforced by the size of the peak-to-peak light variations in EC 20058 − 5234, which are ≤0.05 mag. Even after correcting by the scale factor of 1.4, this is substantially smaller than the total light variations seen in any of the other DBV stars, as may be gauged by inspecting the light curves in the papers cited in Table 1.

(ii) The longest period given in Table 3 is 351 s, approximately equal to the shortest periodicity in any previously known DBV. The shortest period, 111 s, is very similar to the shortest period seen in the DAV stars.

(iii) In the context of the DB oscillators, the grouping of the four strongest modes in two apparent doublets is highly unusual.

(iv) The amplitude spectra appear to be relatively stable compared with other DBVs, although there is some variability both in the total power and in the distribution of power over frequency. In particular, the amplitude of the largest peaks during the CCD run on JD 9562 are the lowest observed amongst the observing runs listed in Table 2.

Because of the low amplitudes and short periods of the oscillations, the pulsation properties of EC 20058 − 5234 are more like those of the low-amplitude DAV pulsators than those of the larger amplitude DBV stars.

4 DISCUSSION

In view of the systematic patterns of periods in the already known DBV stars listed in Table 1, and the success of identifying the modes in GD 358 in particular (Winget et al. 1994), it is interesting to compare the periods in EC 20058 − 5234 with these other stars. In this discussion, we assume that the values of k for GD 358 are also correct for the closest periods in the other stars.

Assuming as a first hypothesis that the periods in EC 20058 − 5234 are successive values of k with $\ell=1$, we can identify the 351-s period in EC 20058 − 5234 with the 354-s period in KUV 5124 + 2604 and assign $k=6$. In this scheme, f_0 to f_5 in Table 3 then correspond to $k=6$ to $k=1$. The modes f_6 and f_7 must then be ascribed to non-linear coupling (note that $f_6=f_2+f_3$ and $f_7=f_3+f_5$). The period spacing in EC 20058 − 5234 between these successive modes (starting at f_0) is 18, 52, 24, 53 and 9 s (average 31 s). This may be compared to the pattern 37, 33, 43, 40, 41, 35, 40, 38 and 41 s (average 39 s) exhibited by GD 358. EC 20058 − 5234 clearly shows different behaviour. Of course, a contributing factor is that, with such low values of k, the asymptotic formula, which implies equal period spacing, is not applicable. The non-systematic pattern of period spacings implies, however, that there are other differences.

We pursue the possibility that the periods in EC 20058 − 5234 are nevertheless all $\ell=1$ modes. To do this, we must invoke a large mass for the star in order to reduce

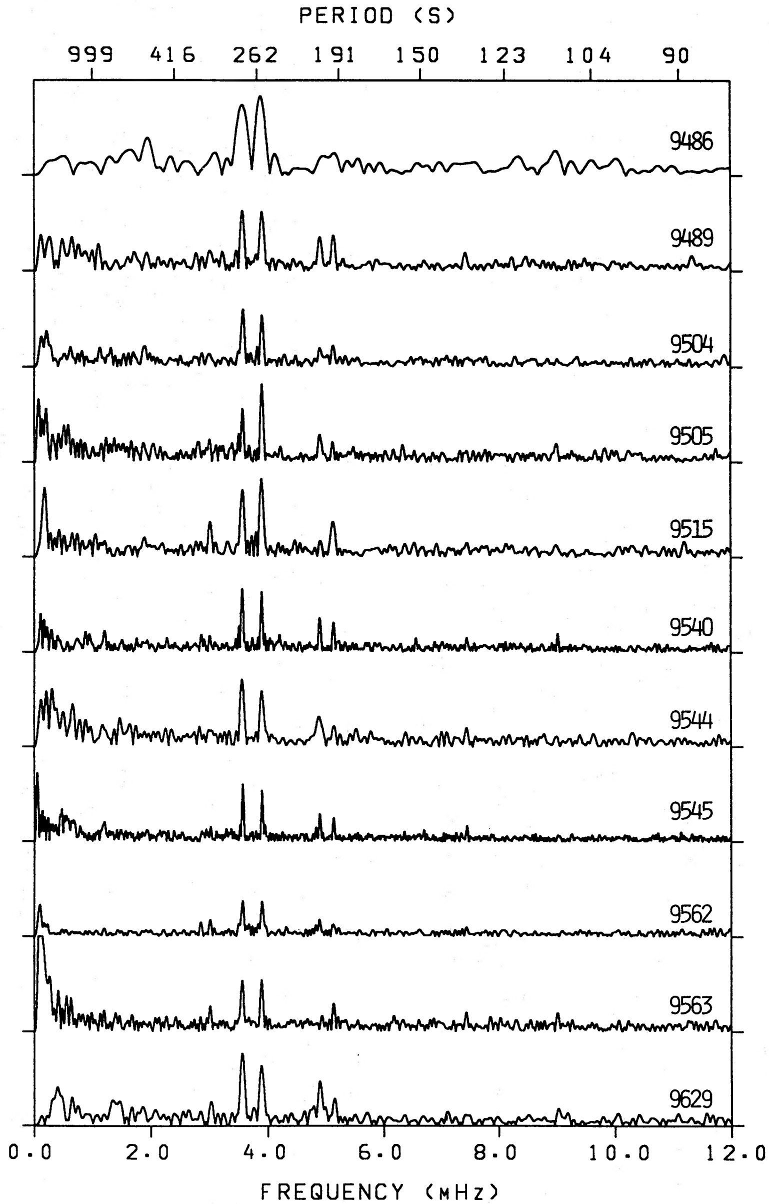

Figure 5. The amplitude spectra of all the runs. The vertical scales are the same for all plots, namely 15 mmag. The spectra are shown in the same order as the runs in Table 2.

Table 3. The amplitudes (in mmag) of repeating periodicities present in the runs catalogued in Table 1. Each run is labelled by the Heliocentric Julian date at its start.

Frequency (mHz)	Period (sec)	9486	9489	9504	9505	9515	9540	9544	9545	9562	9563	9629
$f_0 = 2.84 - 2.86$	351			2.2		2.4	2.8		1.6	2.4	2.5	2.3
$f_1 = 2.99 - 3.02$	333		3.1	2.1	3.6	5.6	2.6		2.4	2.8	4.3	3.8
$f_2 = 3.55 - 3.57$	281	11.2	9.6	9.1	8.5	10.8	10.1	10.8	9.2	6.1	8.7	11.6
$f_3 = 3.89 - 3.90$	257	12.7	9.3	8.1	12.5	12.6	9.6	8.9	8.1	5.9	8.8	9.7
$f_4 = 4.88 - 4.90$	204		5.3	2.9	4.3	2.6	5.4	4.8	4.5	2.8		7.2
$f_5 = 5.12 - 5.14$	195	3.6	5.6	3.3	3.1	5.6	4.7	3.3	3.8	2.0	4.8	4.3
$f_6 = 7.44 - 7.46$	134		2.8		1.8	2.3	2.2	3.0	2.5	1.5	3.3	
$f_7 = 9.00 - 9.03$	111	3.9			2.9	1.8	2.9	1.6			3.1	2.7

Notes. Frequencies close to f_0 were also observed in runs 9489 ($f = 2.87$ mHz, amplitude 2.2 mmag), 9505 ($f = 2.88$ mHz, amplitude 1.8 mmag) and 9544 ($f = 2.82$ mHz, amplitude 3.3 mmag; $f = 2.90$ mHz, amplitude 2.0 mmag).
The two highest frequencies appear to be sums of lower frequencies: $f_6 = f_2 + f_3$ and $f_7 = f_3 + f_5$.
The run labelled 9544 showed peaks of 2.7 and 2.6 mmag at the frequencies 2.98 and 3.03 mHz, rather than the single peak at about 3.0 mHz evident in all other long runs.

Table 4. Low-frequency modes extracted from the filtered series (see text).

Frequency (mHz)	Period (sec)	Number of Runs (out of 10)
0.61 - 0.65	1587	8
0.74 - 0.78	1315	6
1.20 - 1.24	820	8
1.51 - 1.54	656	5
1.89 - 1.93	524	7
2.10 - 2.14	472	8
2.22 - 2.24	435	5
2.77 - 2.81	358	6

the mean period spacing. In addition, in order to explain the very short trapping cycle (alternating small and large period spacing), a thick He layer would be required. Finally, the large spread in period spacing (from 9 to 53 s) would require a very sharp He layer transition zone. These requirements are not satisfied by any of the models shown in Bradley, Winget & Wood (1993).

A second possibility is that only $\ell=2$ modes are selectively excited; the asymptotic period spacing for $\ell=2$ is 23 s (Winget et al. 1994), which would explain the spacing of f_2 to f_3 (24 s) and of f_6 to f_7 (23 s). However, the 9-s separation between f_4 and f_5 remains a difficulty. In principle, such a short period spacing could be ascribed to mode trapping; but in none of the models shown in Bradley et al. (1993) is there a period spacing as short as 9 s.

A third and obvious alternative is that a mixture of different ℓ values is observed. A very wide variety of period spacing is then possible, particularly if the excitation of different k-valued modes is selective. It seems pointless to pursue this avenue until several more modes have been identified.

We should also consider the possibility that the appearance of the four most prominent modes as two doublets is due to mode splitting by magnetic fields or rotation. In contrast to rotational splitting, which gives rise to $2\ell+1$ components, magnetic fields cause $\ell+1$ components to appear (Unno et al. 1979; Jones et al. 1989). If the four modes do in fact consist of two period doublets (257, 281) and (195, 204), this could be due to magnetic splitting of two $\ell=1$ modes. Jones et al. (1989) have published some relevant results; their calculations were done for a stellar model chosen to resemble a DBV star. Inspection of their fig. 1 shows that, for a period of about 270 s, the splitting due to a dipole field of is of the order of 10^{-3} mHz. Since the frequency splitting scales as the field strength squared, a spacing of 0.33 mHz would imply a field of 1.8×10^6 gauss (G). (The referee, D. Winget, has pointed out that a field of only 10^5 G is sufficient to 'freeze in' convection and thus probably suppress the pulsations). It is unfortunately not possible to interpret the other period pair in the light of Jones et al. (1989), as their calibration did not include such short periods, and it is not clear whether extrapolation of their results is justified. If the tendency in their graph applies to short-period pulsators as well, the frequency separation is a very rapidly decreasing function of period, and the

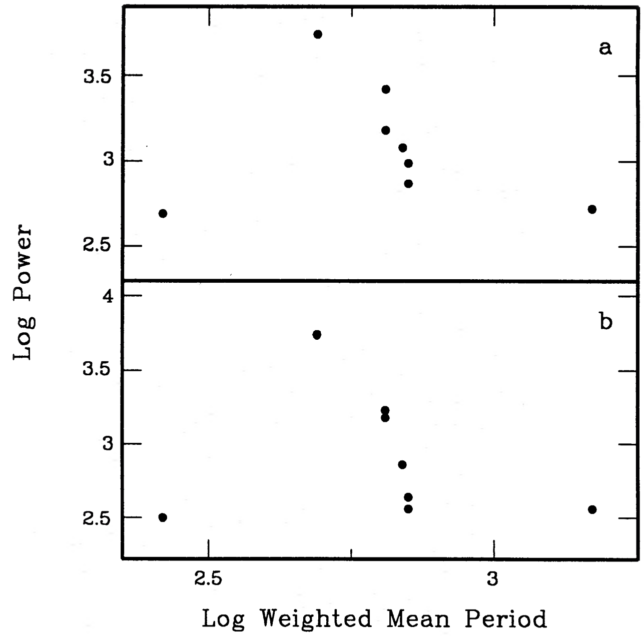

Figure 6. Plots of (a) the total power, and (b) the power in the largest amplitude mode, versus the weighted mean period, for all DBVs. EC 20058 − 5234 and PG 1115 + 158 are represented by the points in the lower left and lower right corners, respectively.

observed difference of 0.24 mHz between f_4 and f_5 at $P\sim200$ s would definitely not accord with the 0.33-mHz separation at $P\sim270$ s. Hence, the case for magnetic mode splitting is undecided on the basis of the available information, particularly as there is no evidence for Zeeman splitting of the He I lines in Fig. 1.

If the prominent doublets are due to rotational splitting, their frequency splitting should be related (see Winget et al. 1991, appendix). The observed splittings are $f_5-f_4=0.24$ mHz and $f_3-f_2=0.33$ mHz. The ratio, 0.73, does not agree with any of the plausible applications of the asymptotic rotational splitting formula, but the values of k are likely to be far from the asymptotic limit.

5 CONCLUDING REMARK

Clemens (1993) showed that log–log plots of total oscillation power in all 'real' modes versus the mean period for DAVs are approximately linear with positive slope. ('Real' modes exclude those due to, e.g., non-linear coupling or rotational splitting. The mean period is calculated by weighting each mode by its power.) The explanation given is in terms of the mass of the partial ionization zone driving the oscillations: a larger mass implies both more power in the oscillations and a longer thermal time-scale, and hence a longer period. Saturation of the driving mechanism is invoked to explain the similar appearance of the log–log plot of the power of the strongest mode against mean period (Clemens 1993). Fig. 6 shows similar plots for the DB pulsators, based on the data in Table 1; note that the EC 20058 − 5234 magnitudes were corrected for the presence of the close companion stars in the aperture, by multiplying by the factor 1.4. It is interesting that the previously known stars appear to behave in the oppposite sense to the ZZ Ceti stars; i.e. the longer the mean

period, the less the power in the oscillations. The newly discovered EC 20058 − 5234 substantially increases the range of observed values, and annoyingly refuses to cooperate in establishing any clear pattern in these diagrams.

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