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Two new pulsating hot subdwarf stars from the Edinburgh-Cape survey

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ABSTRACT

We report the discovery of very rapid pulsations in two hot subdwarf stars from the Edinburgh-Cape blue object survey. The short periods, small amplitudes and multiperiodicity establish these stars as members of the class of rapidly-pulsating sdB stars. The spectrograms of both stars, however, show relatively strong He II 4686 and they are therefore more properly classified as sdOB. The light curve of EC 01541−1409 is dominated by two strong (∼1 per cent) variations with frequencies near 7114 and 7870 μHz (periods near 140.6 and 127.1 s), though at least five frequencies are present with amplitudes above about 0.002 mag. The light curve of EC 22221−3152 appears to be generated by at least 10 frequencies in the range 5670–11850 μHz (about 175–85 s) with amplitudes between about 0.01 and 0.001 mag, including the first overtone of the strongest variation. Somewhat surprisingly, this number of frequencies is detectable in observing runs as short as 3 h, probably due to the fact that the detected frequencies are well-separated.

Key words: stars: individual (EC 01541−1409, EC 22221−3152) – stars: oscillations – stars: variables.

1 INTRODUCTION

A detailed description of the Edinburgh-Cape (EC) blue object survey and the photometric/spectroscopic results for almost a thousand stars in the first EC zone have been published by Stobie et al. (1997) and Kilkenny et al. (1997b), respectively. A substantial result from the survey was the discovery of a new class of pulsating star, tentatively called the EC 14026 stars, after the prototype, EC 14026−2647 (Kilkenny et al. 1997a), although they are more officially known as V361 Hya stars (Kazarovets, Samus & Durlevich 2000) and the shorter and more descriptive name, sdBV stars, seems to be increasing in popularity. These are sdB stars which pulsate with very short periods (typically ∼2 to 3 min) and are believed to be *p*-mode pulsators. They usually have several oscillation frequencies (in some cases over 40 frequencies have been detected); they have surface temperatures around $28\,000 < T_{\rm eff} < 35\,000$ K and surface gravities $5.2 < \log g < 6.1$. Recent reviews of the observational and theoretical work on pulsating sdB stars have been given by Kilkenny (2007) and Charpinet et al. (2007), respectively.

The pulsating sdB stars are important as they provide potential for examining the internal structure of hot subdwarfs – or extended horizontal branch stars – via identification of pulsation modes (see Charpinet et al. 2008 and Van Grootel et al. 2008 for recent examples of this process), and for potentially determining the rate of evolution via secular frequency changes caused by radius/mean density changes. In addition, Kilkenny et al. (2003) attempted to use phase shifts in the pulsations of the sdB star in the binary system PG 1336−018 to measure the size of the binary orbit. Much more successfully and spectacularly, Silvotti et al. (2007) detected a giant planet orbiting the sdBV star HS 2201+2610 (V391 Peg) by measuring timing shifts in the pulsations due to stellar motion around the barycentre.

The discovery of new stars is desirable to extend the sample of stars for such analyses; to test the existence of an 'instability strip' or preferred temperature zone for pulsation; and to test the detected frequencies against pulsation models. In this context, the recent discovery of a separate, somewhat cooler group of *slowly* pulsating sdB stars – the V1093 Her (or PG 1716+426) stars – by Green et al. (2003) is very exciting. These stars are multiperiodic *g*-mode pulsators with periods of the order of an hour. Additionally, three fascinating stars have recently been found to exhibit *both p*- and *g*-mode variations (see e.g. Oreiro et al. 2004; Schuh et al. 2006; Lutz et al. 2008).

Here, we present results which show two more EC hot subdwarf stars to belong to the class of rapid pulsators. After many weeks of searching for new variables, these stars were discovered on successive nights! Some basic details are given in Table 1; the 1950

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Table 1. New Edinburgh-Cape pulsating hot subdwarfs.

EC	α_{2000} (h min s)	δ_{2000} (° arcmin arcsec)	B_{pg}	Type
01541−1409	01 56 31	−13 54 27	12.1	sdOB
22221−3152	22 24 56	−31 37 19	13.4	sdOB

co-ordinates are implicit in the object names. Both stars are from the unpublished South Galactic Cap part of the survey and we do not as yet have *UBV* photometry.

2 LOW-DISPERSION SPECTROSCOPY

As part of the EC survey, low-dispersion spectrograms of both EC 01541−1409 and EC 22221−3152 were obtained with the South African Astronomical Observatory (SAAO) 1.9-m telescope and Cassegrain spectrograph using grating 6 which gives ∼100 Å mm^{-1}. These are illustrated in Fig. 1 and are approximately flux-calibrated. Accurate absolute calibration is impossible because of the spectrograph slit which makes atmospheric seeing a factor, and because we usually only measure a spectrophotometric standard at the start of the night, so variations in transparency could affect the flux. (Even the relative flux values might be affected if there were wavelength-dependent slit effects).

The spectrograms in Fig. 1 show Balmer series hydrogen lines which are broad (only visible to about $n = 10$ or 11), and a He I 4471 line which is much stronger than He I 4387 (the latter is essentially undetectable in EC 22221−3152); both phenomena are typical of subdwarf B stars. But, in both stellar spectra, He II 4686 is clearly visible and is stronger than He I 4387 or 4713 – a property of sdOB stars (see e.g. the archetypal spectrograms displayed in fig. 1 of Moehler et al. 1990).

Amongst the pulsating sdB stars, these new discoveries are perhaps comparable with the relatively helium-strong PG 1219+534 (see fig. 5 of Heber, Reid & Werner 2000) which also clearly shows He II 4686. However, in the latter star, He II 4686 is comparable

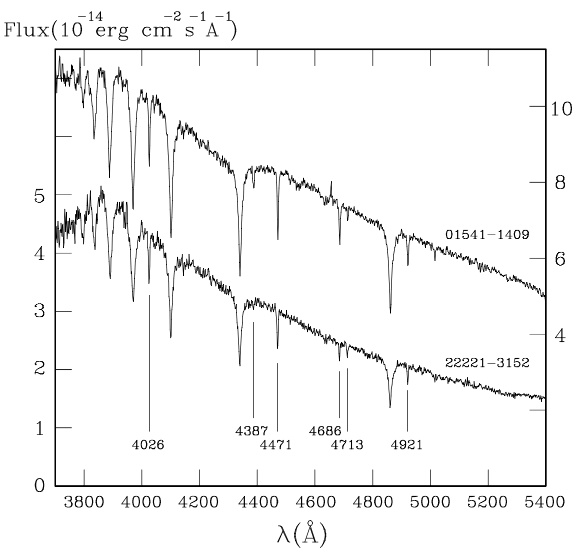

Figure 1. Low-dispersion spectrograms of EC 01541−1409 (upper) and EC 22221−3152 (lower). The location of He II 4686 and several neutral He lines are indicated. The left ordinate scale refers to EC 22221−3152 and the right to EC 01541−1409, though absolute flux values are not reliable (see text).

Table 2. Photometry logs. I is the integration time for each run.

Star	Date (2007)	JD	I (s)	Length (h)
EC 01541−1409	October 16/17	2 454 390	10	3.2
	October 17/18	2 454 391	12	3.5
	October 30/31	2 454 404	10	3.7
	November 07/08	2 454 412	6	1.3
	November 08/09	2 454 413	20	2.5
EC 22221−3152	October 15/16	2 454 389	10	3.1
	October 16/17	2 454 390	10	4.4

in strength to He I 4713 whereas in EC 22221−3152, He II 4686 appears somewhat stronger and in EC 01541−1409 very much stronger than the He I line. Heber, Reid & Werner (2000) determine $T_{\rm eff} = 34\,300$ K for the PG star and if these new stars prove to be significantly hotter, they would be the hottest known rapidly pulsating sdB/sdOB stars (see fig. 9 of Charpinet, Fontaine & Brassard 2001, for example). We plan to obtain better signal-to-noise spectrograms than we currently possess in order to make accurate temperature determinations.

3 CONTINUOUS PHOTOMETRY

The photometric data described in this paper were obtained with the University of Cape Town Wright Instruments CCD photometer (UCTCCD – described by O'Donoghue 1995) on the 1.0-m telescope at the Sutherland site of the SAAO. Different integration times were used, as indicated in Table 2 (there is no dead-time with the CCD as it is operated in frame transfer mode). No optical filter was used (all observations were in 'white light') and a list of some observational details is given in Table 2. The observations of EC 22221−3152 on 2007 October 16/17 actually extend over a baseline of about 4.9 h, but an instrumental problem caused two short gaps in the data amounting to about half an hour in total.

Reduction of the CCD frames can be performed on-line, which enables the observer to judge the quality of the observations and to select suitable stars as local comparisons (to correct for small transparency variations). Conventional procedures (bias subtraction, flat field correction and so on) were followed, with magnitude extraction being based on the DOPHOT program described by Schechter, Mateo & Saha (1993).

In the cases of both stars described here, there exists a single suitable (but somewhat fainter) star in the rather small field of view of the UCTCCD. Each was used to correct differentially the appropriate target star on every night. Because 'random' field stars will have a strong tendency to be very much redder than sdB stars, we have corrected for differential extinction effects by fitting a second order polynomial to any long-term trends in the data. This means that we might be removing real changes in stellar brightness, but since with 'high speed' photometry we often cannot distinguish between such effects and small atmospheric changes on time-scales longer than about 0.5 h, this has to be accepted. (In general, a simple quadratic fit seems to be remarkably effective at 'flattening' the effect of differential extinction, even on rather long runs, which start and end at quite high air masses).

4 FREQUENCY ANALYSES

The frequency analyses described in this section were all carried out using software written by one of us (DO'D) which produces

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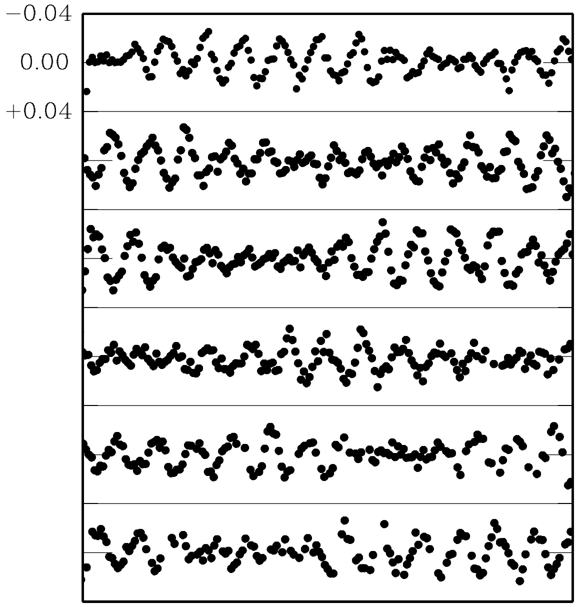

Figure 2. Sample data for EC 01541−1409 from 2007 October 30/31. Panels are 0.02-d (∼29 min) long and read from top to bottom and left to right. The ordinates are in magnitude units and the data displayed run from JD 2 454 404.39 to 2 454 404.51.

periodogram analysis following the Fourier transform method of Deeming (1975) as modified by Kurtz (1985).

4.1 EC 01541−1409

Fig. 2 shows a typical section of light curve for EC 01541−1409. It is immediately apparent that the star has quite a large amplitude for an sdB pulsator. It is also clear that the star has at least two modes of observation and probably more, based on the fact that the beating does not exhibit an exactly repeating pattern.

Fig. 3 shows periodograms for a sample of three individual nights in 2007 October. It can be seen that the light curve is dominated by two strong peaks near 7120 and 7870 μHz (periods of about 140 and 127 s) but that there are other, weaker frequencies present. Removal of peaks one at a time from each of the five nights listed in Table 2 reveals three frequencies which are clearly present in all five nights (near 7120, 7870 and 9080 μHz; equivalent to periods of 140, 127 and 110 s); two frequencies which appear in four nights (near 8570 and 12740 μHz; 117 and 78 s); and one which appears in three nights (6855 μHz; 146 s).

Given that these observing runs were all short – 3 h is typical – and that the resolution of such runs (determined as 1.5/T; Loumos & Deeming 1978) will be about 150 μHz, it makes sense to try to analyse the data by combining nights. In the case of EC 01541−1409, four observing runs occur as two sets from adjacent nights (October 16/17 + 17/18 and November 7/8 + 8/9) and we have reduced and compared these. With a baseline of about a day, the resolution of the paired data sets will be about 15 μHz. Initially, we removed frequencies one at a time, finding that the first five frequencies in each (paired) set of data agreed closely (though not in exactly the same order of decreasing amplitude) and that all of these frequencies are listed in the previous paragraph as having appeared in all or most of the analyses of single nights. We then removed those five frequencies simultaneously from each set using a Taylor expansion non-linear least-squares technique and searched for further common frequencies. In fact, there appears to be little else of significance, except perhaps a weak frequency near 12750 μHz (period of about 78.4 s) which is just visible at the right-hand end of the periodograms in Fig. 4.

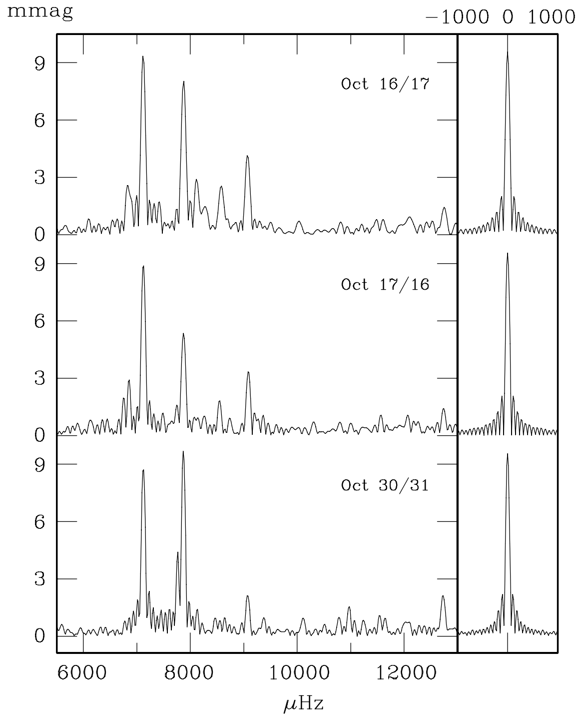

Figure 3. Periodograms for individual 2007 October runs on EC 01541−1409. The corresponding window functions of the data are shown in the right-hand panels.

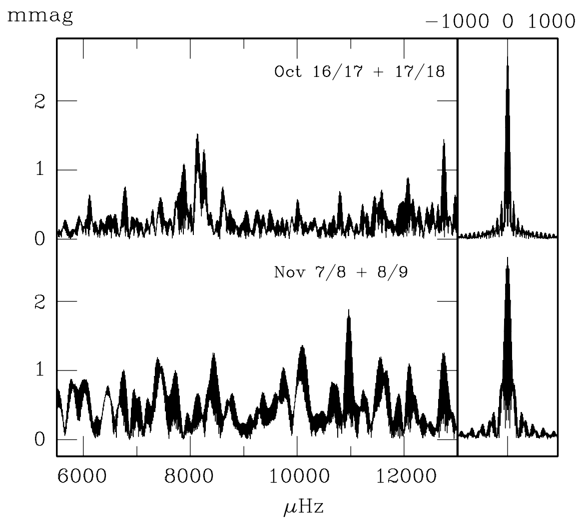

Figure 4. Periodograms for EC 01541−1409 for paired nights (October 16/17 + 17/18 and November 7/8 + 8/9) *after* subtraction of the five strongest frequencies. The corresponding window functions of the data are shown in the right-hand panels.

Note that the background (rms) noise levels in Fig. 4 are about half a millimag in the bottom panel and much less than that in the top panel. The canonical ‘four times background noise’ for reality for variations is therefore easily met by the strongest five frequencies in Table 3 (even if we ignore the fact that those frequencies are detected in two separate data sets). The 12 750 μHz frequency does not meet that criterion, though the frequency does appear in both

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Table 3. Frequencies and amplitudes for EC 01541−1409 from the paired nights in 2007 October and November reduced separately. Figures in brackets are formal errors in frequency from the least squares fitting procedures. The errors in amplitude are ∼0.2 mmag for October and ∼0.3 mmag for November.

October 16/17 + 17/18		November 7/8 + 8/9		
Frequency (μHz)	Amplitude (mag)	Frequency (μHz)	Amplitude (mag)	P (s)
7117.2 (0.1)	0.0092	7110.8 (0.1)	0.0095	140.6
7872.9 (0.1)	0.0068	7865.5 (0.3)	0.0046	127.1
9075.5 (0.2)	0.0037	9082.6 (0.5)	0.0026	110.1
6859.1 (0.3)	0.0024	6864.2 (0.7)	0.0020	145.7
8553.1 (0.4)	0.0020	8575.3 (0.5)	0.0026	116.8
12 745.9 (0.7)	0.0015	12 750.9 (1.5)	0.0013	78.4

data sets. We initially worried that this might be due to the 80-s drive error of the telescope but we find power at 39.93 s (25 044 μHz) and this indicates that the '80 s' signal would be at 12 522 μHz, which seems a little too distant from the 12 750 to be the same. Even so, we regard this frequency with some caution.

4.2 EC 22221−3152

Fig. 5 shows a section of light curve from 2007 October 15/16 for EC 22221−3152; again, it is clear that the star is multiperiodic and has substantial amplitude of variation for an sdB pulsator.

Proceeding in the same manner as for EC 01541−1409, we were astonished to be able to extract 11 frequencies – apparently well above noise – from the first run of only 3.1 h. This would hardly be believable, except for the fact that the second run (of 4.4 h) on the next night yielded exactly the same 11 frequencies in closely similar (though not exact) order of decreasing amplitude. The periodograms for the separate nights are shown in Figs 6 and 7, where the data have been pre-whitened by the strongest six frequencies. In Fig. 7, even

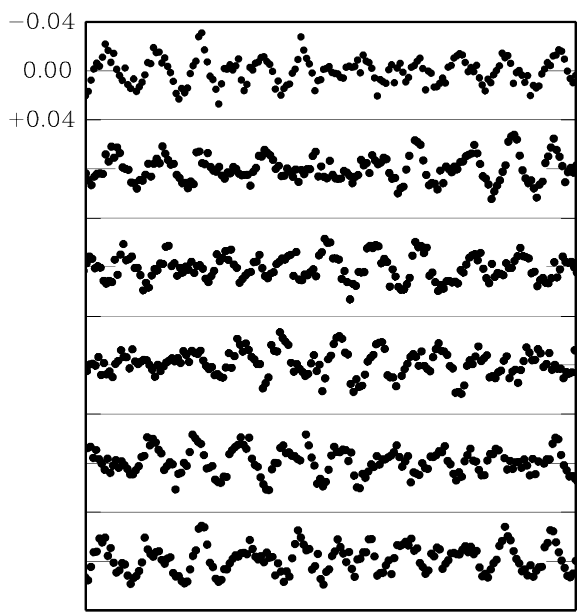

Figure 5. Sample data for EC 22221−3152 from 2007 October 15/16. Panels are 0.02-d (∼29 min) long and read from top to bottom and left to right. The ordinates are in magnitude units and the data displayed run from JD 2 454 389.31 to 2 454 389.43.

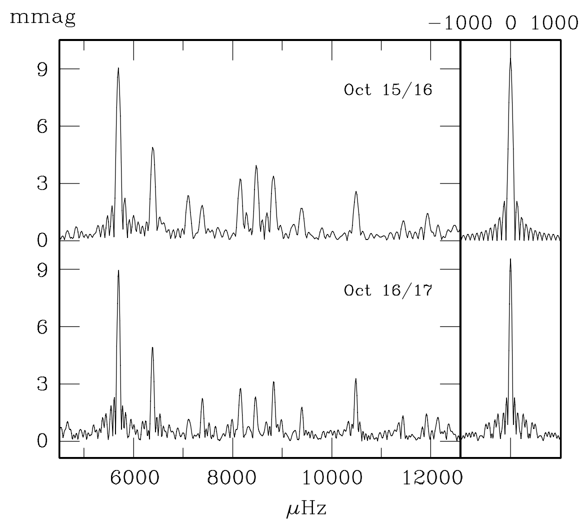

Figure 6. Periodograms for individual 2007 October runs on EC 22221−3152. The corresponding window functions of the data are shown in the right-hand panels. (The somewhat different appearance of the window function for the 16/17 is due to two small gaps in the data caused by minor instrumental problems.)

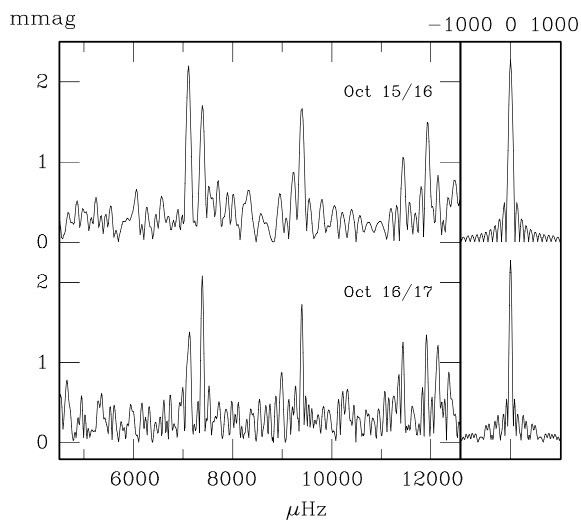

Figure 7. Periodograms for individual 2007 October runs on EC 22221−3152 but with the data pre-whitened by the six strongest frequencies. The corresponding window functions of the data are shown in the right-hand panels.

to the eye, it appears that there are at least another five frequencies which are very similar in the two runs. This is confirmed in Table 4 which lists the 11 strongest frequencies extracted simultaneously from each night. Nearly all of the results from the two nights are in very good agreement (compared to the formal errors in frequency) – and all are in good agreement if one allows for aliasing. For example, the two results for f_{10} are different by 27 μHz whereas a 2 cycle d^{-1} difference would be ∼23 μHz.

The background noise levels (rms) in the two periodograms are ∼0.3 millimag (see Fig. 7), so that essentially all of the extracted frequencies are above four times the noise. The weakest frequency, f_{11} in Table 4, is almost exactly twice the frequency of f_1 and is presumably the second harmonic and probably reflects the fact that f_1 is not a sinusoidal variation.

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Table 4. Frequencies and Amplitudes for EC 22221−3152 from the two nights 2007 October 15/16 and 16/17 reduced separately. Figures in brackets are the formal errors in frequency from the least squares fitting procedure. Errors in amplitude are ∼0.2 mmag for the 15/16 and ∼0.4 mmag for the 16/17.

	15/16		16/17		
	Frequency (μHz)	Amplitude (mag)	Frequency (μHz)	Amplitude (mag)	P (s)
f_1	5678 (1)	0.0090	5679 (1)	0.0089	176.1
f_2	6366 (2)	0.0048	6359 (3)	0.0046	157.2
f_3	8427 (3)	0.0035	8423 (3)	0.0025	118.7
f_4	8776 (3)	0.0035	8770 (4)	0.0031	114.0
f_5	8106 (4)	0.0031	8112 (4)	0.0030	123.3
f_6	10418 (5)	0.0025	10415 (4)	0.0032	96.0
f_7	7080 (5)	0.0022	7098 (11)	0.0011	141.1
f_8	9337 (7)	0.0017	9339 (7)	0.0017	107.1
f_9	7345 (7)	0.0017	7351 (6)	0.0020	136.1
f_{10}	11846 (7)	0.0015	11819 (9)	0.0014	84.5
f_{11}	11 359 (10)	0.0011	11 354 (10)	0.0012	88.1

5 SUMMARY

We have shown that EC 01541−1409 and EC 22221−3152 are rapid pulsators of the EC14026 (sdBV) class. Both stars have relatively high amplitude variations which are resolved into a number of frequencies – at least five in the case of EC 01541−1409 and at least 11 for EC 22221−3152 (including the first overtone of the strongest pulsation). Both stars clearly exhibit the He II line at 4686 Å – in EC 01541−1409, it is particularly strong – which more properly makes the stars of sdOB type. Finally, both stars might be useful in searching for phase shifts or (O–C) shifts because the detected frequencies appear well-separated (though we cannot examine frequency/amplitude stability with the small data set currently available).

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REFERENCES

Charpinet S., Fontaine G., Brassard P., 2001, PASP, 113, 775
Charpinet S., Fontaine G., Brassard P., Chayer P., Green E. M., Randall S. K., 2007, in Handler G. Houdek G., eds, Communications in Asteroseismology, Vol 150, The Future of Asteroseismology. Austrian Acad. Sci., Vienna, p. 241
Charpinet S., van Grootel V., Fontaine G., Brassard P., Green E. M., Chayer P., Randall S. K., 2008, A&A, 489, 377
Deeming T. J., 1975, Ap&SS, 36, 137
Green E. M. et al., 2003, ApJ, 583, L31
Heber U., Reid I. N., Werner K., 2000, A&A, 363, 198
Kazarovets E. V., Samus N. N., Durlevich O. V., 2000, IBVS, 4870
Kilkenny D., 2007, in Handler G., Houdek G., eds, Communications in Asteroseismology, Vol 150. The Future of Asteroseismology. Austrian Acad. Sci., Vienna, p. 234
Kilkenny D., Koen C., O'Donoghue D., Stobie R. S., 1997a, MNRAS, 285, 640
Kilkenny D., O'Donoghue D., Koen C., Stobie R. S., Chen A., 1997b, MNRAS, 287, 867
Kilkenny D. et al., 2003, MNRAS, 345, 834
Kurtz D. W., 1985, MNRAS, 213, 773
Loumos G. L., Deeming T. J., 1978, Ap&SS, 56, 285
Lutz R. et al., 2008, in Heber U., Napiwotzki R., Jeffery C. S., eds, Proc. ASP Conf. Ser. Vol. 392, Hot Subdwarf Stars and Related Objects. Astron. Soc. Pac., San Francisco, p. 339
Moehler S., Richtler T., de Boer K. S., Dettmar R. J., Heber U., 1990, A&AS, 86, 53
O'Donoghue D., 1995, Balt. Astron., 4, 519
Oreiro R., Ulla A., Pérez Hernández F., Rodrguez López C., MacDonald J., 2004, A&A, 418, 243
Schechter P. L., Mateo M., Saha A., 1993, PASP, 105, 1342
Schuh S., Heber U., Dreizler S., O'Toole S., Green E., Fontaine G., 2006, A&A, 445, L31
Silvotti R. et al., 2007, Nat, 449, 189
Stobie R. S. et al., 1997, MNRAS, 287, 848
Van Grootel V., Charpinet S., Fontaine G., Brassard P., Green E. M., Chayer P., Randall S. K., 2008, A&A, 488, 685

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