Amplitude and frequency variability of the pulsating DB white dwarf stars KUV 05134+2605 and PG 1654+160 observed with the Whole Earth Telescope

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ABSTRACT

We have acquired new time series photometry of the two pulsating DB white dwarf stars KUV 05134+2605 and PG 1654+160 with the Whole Earth Telescope. Additional single-site photometry is also presented. We use all these data plus all available archival measurements to study the temporal behaviour of the pulsational amplitudes and frequencies of these stars for the first time.

We demonstrate that both KUV 05134+2605 and PG 1654+160 pulsate in many modes, the amplitudes of which are variable in time; some frequency variability of PG 1654+160 is also indicated. Beating of multiple pulsation modes cannot explain our observations; the amplitude variability must therefore be intrinsic. We cannot find stable modes to be used for determinations of the evolutionary period changes of the stars. Some of the modes of PG 1654+160 appear at the same periods whenever detected. The mean spacing of these periods ($\approx$40 s) suggests that they are probably caused by non-radial gravity-mode pulsations of spherical degree $\ell = 1$. If so, PG 1654+160 has a mass around $0.6\,\mathrm{M}_\odot$.

The time-scales of the amplitude variability of both stars (down to two weeks) are consistent with theoretical predictions of resonant mode coupling, a conclusion which might however be affected by the temporal distribution of our data.

Key words: stars: individual: KUV 05134+2605 – stars: individual: PG 1654+160 – stars: oscillations – stars: variables: other.

1 INTRODUCTION

In recent times it has become clear that amplitude and frequency variations are common amongst pulsating stars. Various mechanisms for their explanation have been proposed. For example, resonant mode interaction (Moskalik 1985) is consistent with observations of this phenomenon in δ Scuti stars (e.g. Handler et al. 1998, 2000), whereas frequency changes of rapidly oscillating Ap stars may be attributed to variations in the magnetic field (Kurtz et al. 1994, 1997).

Time-resolved photometric observations of pulsating (pre-)white dwarf stars revealed that they are no exception in this respect. This bears a potentially enormous astrophysical reward: although these stars may only make part of their pulsation spectra observable to us at a given time, they may reveal their complete mode spectrum when observed persistently. Kleinman et al. (1998), Bond et al. (1996) and Vauclair et al. (2002) took advantage of this possibility and could then make seismic analyses for a pulsating DA white dwarf (G29-38) and two pulsating central stars of planetary nebulae (NGC 1501, RXJ 2117+3412). Without their amplitude variability, these stars would still be poorly understood.

Published reports of amplitude and frequency variations are still sparse for the helium-atmosphere pulsating DB white dwarf stars

(DBVs, see Bradley 1995, for a review), but so are their time-series photometric observations, mainly due to their faintness (most DBVs are around 16$^{\text{th}}$ magnitude). The glaring ($B = 13.5$) exception is the prototype DBV GD 358 for which a plethora of measurements, including three Whole Earth Telescope (WET, Nather et al. 1990) runs, is available. Although the mode amplitudes of GD 358 vary, the associated pulsation frequencies seem reasonably stable (Kepler et al. 2003). Very recently, some amplitude and frequency variations have also been reported for the DBVs CBS 114 and PG 1456+103 (Handler, Metcalfe & Wood 2002).

We have started a systematic observing program to obtain reliable frequency analyses of the mode spectra of all pulsating DB white dwarfs. Our measurements consist of extensive single-site observations, which can suffice for very simply-behaved objects (Handler 2001), or low-priority WET observations (this paper), or even full worldwide multisite campaigns.

2 OBSERVATIONS AND REDUCTIONS

The pulsating DB white dwarf stars KUV 05134+2605 and PG 1654+160 were chosen as secondary target stars for the WET runs Xcov20 and Xcov21 during 2000 November and 2001 April,

Table 1. Time-series photometry of KUV 05134+2605. The first part of the table contains the WET measurements, the second part lists additional single-site observations, and the third part contains the available discovery data (Grauer et al. 1989). Runs marked with asterisks were obtained with a CCD.

Run name	Obs./Tel.	Date (UT)	Start (UT)	Length (h)
asm-0080	McD 2.1 m	2000 Nov 20	11:32:40	0.90
asm-0082	McD 2.1 m	2000 Nov 21	10:35:30	1.78
joy-003	McD 2.1 m	2000 Nov 23	10:20:00	2.16
joy-013	McD 2.1 m	2000 Nov 26	08:52:16	3.55
joy-017	McD 2.1 m	2000 Nov 27	10:08:40	2.38
joy-021	McD 2.1 m	2000 Nov 28	07:16:20	5.10
joy-026	McD 2.1 m	2000 Nov 29	09:48:50	2.77
sara-0054*	SARA 0.9 m	2000 Nov 30	04:53:00	8.49
joy-029	McD 2.1 m	2000 Nov 30	09:51:20	2.50
joy-032	McD 2.1 m	2000 Dec 01	09:10:00	3.44
sara-0055*	SARA 0.9 m	2000 Dec 03	05:18:20	8.01
sara-0057*	SARA 0.9 m	2000 Dec 05	03:21:00	5.47
tsm-0088	McD 2.1 m	2000 Dec 05	09:46:00	2.67
KU1229OH	OHP 1.9 m	1992 Dec 29	18:23:00	5.00
KU1230OH	OHP 1.9 m	1992 Dec 30	17:50:00	4.50
gh-0484*	SAAO 1.0 m	2000 Oct 04	00:45:26	2.55
gh-0486*	SAAO 1.0 m	2000 Oct 05	00:42:07	2.02
gh-0488*	SAAO 1.0 m	2000 Oct 06	00:36:43	2.76
gh-0492*	SAAO 1.0 m	2000 Oct 09	00:15:49	3.03
gh-0493*	SAAO 0.75 m	2001 Jan 30	19:01:40	2.40
gh-0496*	SAAO 0.75 m	2001 Jan 31	18:57:10	2.40
gh-0499*	SAAO 0.75 m	2001 Feb 01	18:40:15	2.62
adg-0076	MtB 1.5 m	1988 Oct 12	09:37:20	2.43
adg-0077	MtB 1.5 m	1988 Oct 13	08:23:10	1.67
adg-0080	MtB 1.5 m	1988 Oct 14	06:52:30	1.10
adg-0081	MtB 1.5 m	1988 Oct 14	10:19:20	1.86
adg-0082	MtB 1.5 m	1988 Oct 16	09:45:10	2.48
adg-0084	MtB 1.5 m	1988 Oct 18	07:26:00	1.98
Total WET				49.22
Grand total				88.02

Observatory codes: McD = McDonald Observatory (USA), SARA = Southeastern Association for Research in Astronomy Observatory (USA), OHP = Observatoire de Haute-Provence (France), SAAO = South African Astronomical Observatory, MtB = Steward Observatory (Mt. Bigelow site, USA).

respectively. Such secondary programme stars are observed by the network if the primary target is not observable or if two telescopes are on line and the larger one already measures the primary or if the observing method at a certain site is not suitable for the primary (e.g. CCDs are not proper instruments for very bright stars). Although the temporal coverage of the variations of a secondary target is usually considerably poorer than that of the primary, the resulting data sets are often quite valuable (see Handler et al. 1997 for an example).

In addition to the WET measurements, we acquired single-site observations of KUV 05134+2605 and PG 1654+160 before and/or after the main data stream. In an effort to understand these two stars to the limits currently possible, we also (re)analysed all available published and unpublished measurements. The time-series photometric data at our disposal are listed in Tables 1 and 2.

Most of the observations consisted of multichannel high-speed photoelectric photometry with 10-s integrations (see Kleinman, Nather & Philips 1996, for more information). Channel 1 measured the programme star, channel 2 measured a local comparison star, and

Table 2. Time-series photometry of PG 1654+160. The first part of the table contains the WET measurements, the second part lists additional single-site observations, and the third part reports the available discovery data (Winget et al. 1984). Runs marked with asterisks were obtained with a CCD.

Run name	Obs./Tel.	Date (UT)	Start (UT)	Length (h)
sara-0081*	SARA 0.9 m	2001 Apr 17	10:53:30	1.36
luc02a	LNA 1.6 m	2001 Apr 20	04:36:10	0.36
luc03a	LNA 1.6 m	2001 Apr 20	05:51:10	1.13
luap21c	LNA 1.6 m	2001 Apr 21	03:12:00	2.48
luap21d	LNA 1.6 m	2001 Apr 21	05:43:40	2.32
sara-0083*	SARA 0.9 m	2001 Apr 21	06:52:25	5.33
mdr160	CTIO 1.5 m	2001 Apr 21	08:38:50	1.56
luap22c	LNA 1.6 m	2001 Apr 22	07:10:40	1.11
mdr163	CTIO 1.5 m	2001 Apr 22	09:05:20	1.05
luap23b	LNA 1.6 m	2001 Apr 23	06:42:00	1.75
sara-0085*	SARA 0.9 m	2001 Apr 23	09:48:50	2.26
luap24c	LNA 1.6 m	2001 Apr 24	02:58:00	1.35
luap24d	LNA 1.6 m	2001 Apr 24	04:29:00	0.89
mdr166	CTIO 1.5 m	2001 Apr 24	07:50:30	2.33
luap25b	LNA 1.6 m	2001 Apr 25	03:27:00	2.13
mdr169	CTIO 1.5 m	2001 Apr 25	06:37:00	3.45
gh-0508	SAAO 1.9 m	2001 Apr 26	02:06:40	1.94
luap26b	LNA 1.6 m	2001 Apr 26	03:01:00	5.40
NOTkd25b*	NOT 2.6 m	2001 Apr 26	03:29:00	2.46
mdr172	CTIO 1.5 m	2001 Apr 26	09:03:40	1.14
gh-0509	SAAO 1.9 m	2001 Apr 27	00:59:40	2.83
NOTkd26c*	NOT 2.6 m	2001 Apr 27	01:17:20	4.49
luap27b	LNA 1.6 m	2001 Apr 27	03:12:00	3.49
luap27c	LNA 1.6 m	2001 Apr 27	06:52:00	1.46
mdr175	CTIO 1.5 m	2001 Apr 27	09:05:20	1.06
sara-0092*	SARA 0.9 m	2001 Apr 28	06:22:50	5.73
mdr178	CTIO 1.5 m	2001 Apr 28	07:51:40	2.30
sara-0095*	SARA 0.9 m	2001 Apr 29	06:05:25	5.96
gh-0517	SAAO 1.9 m	2001 May 01	02:07:30	1.90
NOTkd30c*	NOT 2.6 m	2001 May 01	03:49:40	1.84
NOTke02a*	NOT 2.6 m	2001 May 02	23:08:50	5.11
NOTke03d*	NOT 2.6 m	2001 May 04	02:22:42	3.33
r3076	McD 2.1 m	1985 Jun 21	03:39:00	6.61
sjk-0317	McD 0.8 m	1994 Apr 06	06:40:30	5.14
sjk-0319	McD 0.8 m	1994 Apr 07	06:28:00	5.42
pi-001*	PO 1.0 m	2001 May 14	21:27:53	4.59
pi-002*	PO 1.0 m	2001 May 16	22:21:34	3.61
pi-003*	PO 1.0 m	2001 Jun 25	19:49:39	1.89
pi-004*	PO 1.0 m	2001 Jun 26	20:47:06	4.01
pi-005*	PO 1.0 m	2001 Jun 27	20:51:02	2.50
r2817	McD 2.1 m	1983 Aug 02	05:32:46	1.43
r2819	McD 2.1 m	1983 Aug 04	03:27:13	0.47
r2822	McD 2.1 m	1983 Aug 07	03:16:00	3.49
Total WET				81.30
Grand total				120.46

Observatories: SARA = Southeastern Association for Research in Astronomy Observatory (USA), LNA = Osservatório do Pico dos Dias (Brazil), CTIO = Cerro Tololo Interamerican Observatory (Chile), SAAO = South African Astronomical Observatory, NOT = Nordic Optical Telescope (Tenerife), McD = McDonald Observatory (USA), PO = Piszkestetö Observatory (Hungary).

channel 3 simultaneously recorded sky background. If no third channel was available, the measurements were irregularly interrupted to measure sky. Data reduction was performed with a standard procedure, as e.g. described by Handler et al. (1997).

Our CCD measurements were acquired with a number of different photometers – which we do not describe in detail here. The observations were optimized to acquire at least two local comparison stars in the same field as the target by minimizing the readout time, ensuring a duty cycle as high as possible. In this way, consecutive data points were obtained in 10–30 s intervals, depending on the instrument.

CCD data reduction comprised correction for bias, dark counts and flat-field. Photometric measurements on these reduced frames were made with the programs MOMF (Kjeldsen & Frandsen 1992) or RTP (Østensen 2000), and differential light curves were created. No variability of any star other than the targets in the different CCD fields was found, and the comparison star ensemble resulting in the lowest scatter in the target star light curves was chosen.

At this point it should be noted that PG 1654+160 has a companion star (Zuckerman & Becklin 1992) at a separation of about 4″ distance that may affect our measurements. Fortunately for us, this companion is very red. Consequently, we used red-cutoff filters, e.g. a Schott BG 39 glass, which suppressed the companion's contribution sufficiently (it then was ∼2 mag fainter than the target), but did not waste too many photons of the target star. This also means that the companion's flux did not affect the amplitudes of the photoelectrically measured target star light curves significantly, as all our photomultipliers are blue-sensitive.

Finally, the times of measurement were transformed to Barycentric Julian Ephemeris Date (BJED); the barycentric correction was applied point by point. Finally, some overlapping portions of the combined light curves were merged, and the reduced time series were subjected to frequency analyses.

3 FREQUENCY ANALYSIS

Our frequency analyses were mainly performed with the program PERIOD 98 (Sperl 1998). This package applies single-frequency power spectrum analysis and simultaneous multifrequency sine-wave fitting. It also includes advanced options, such as the calculation of optimal light-curve fits for multiperiodic signals including harmonic, combination, and equally spaced frequencies, which are often found in the analysis of the light curves of pulsating white dwarf stars.

In one case to be indicated later, this method was supplemented by a residualgram analysis (Martinez & Koen 1994), which is based on a least-squares fit of a sine wave with M harmonics. One advantage of this method is that alias ambiguities can be evaluated more reliably by the simultaneous inclusion of the information in the Fourier harmonics.

3.1 KUV 05134+2605

We first analysed the WET measurements of KUV 05134+2605 with PERIOD 98. We computed the spectral window of the data (calculated as the Fourier Transform of a noise-free sinusoid with a frequency of 1.902 mHz and an amplitude of 9.7 milli-modulation amplitudes[1] (mma)) followed by the amplitude spectrum itself. The results are shown in the upper two panels of Fig. 1. As the WET measurements were only acquired from North American observatories (a result from the star having second priority), the window function is poor.

[1] One milli-modulation amplitude is the Fourier amplitude of a signal with a fractional intensity variation of 0.1 per cent; it is a standard unit for WET data analysis.
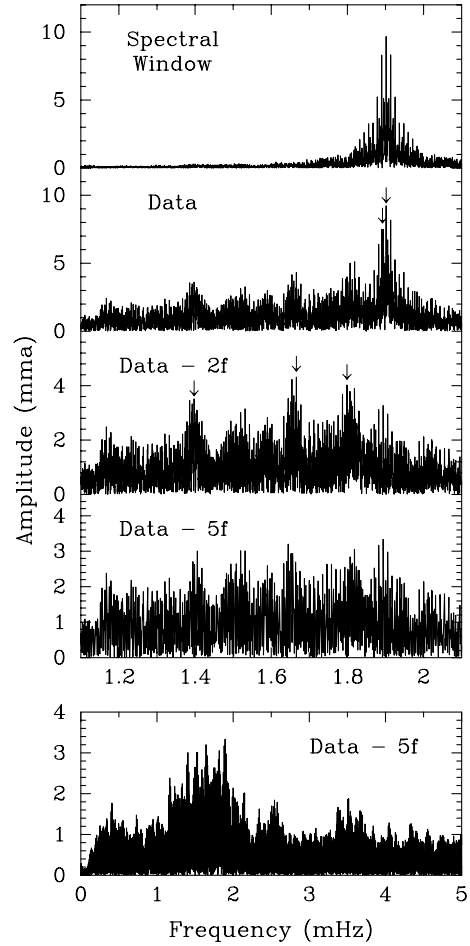

Figure 1. Spectral window and amplitude spectra of the WET measurements of KUV 05134+2605. Some trial prewhitening of the signals indicated with arrows to demonstrate the richness of the frequency spectrum is shown in consecutive panels. Due to the poor spectral window, no frequency can be determined with certainty, but many signals are definitely present in the light curves, as best seen in the lowest panel which shows an extended frequency range.

Still, we show some prewhitening steps in consecutive panels in Fig. 1. This has been done to indicate the main regions in which pulsational signals are present, but definite periods cannot be determined. In any case, it is suggested that KUV 05134+2605 has a rich pulsation spectrum.

This is not the only interesting feature of the pulsations of the star: in the discovery paper (Grauer et al. 1989) it was found to be of much higher amplitude and longer period compared to its pulsational state during the WET run. The star has changed from showing dominant pulsations with time-scales of 710 s and peak-to-peak amplitudes up to 0.2 mag to less than 0.1 mag and a dominant 530-s time-scale (Fig. 2).

We have therefore calculated amplitude spectra of all the available data (Fig. 3). Interestingly, the amplitude spectrum of the star was different every time it was observed. Besides the data discussed before, the measurements from 1992 show a dominant variability time-scale of around 650 s, and the 2001 February data have a prevailing time-scale of 570 s. Only the light curves from October 2000 appear similar to those acquired by the WET some 6 weeks later, but this actually only applies to the signal of highest amplitude. We conclude that KUV 05134+2605 shows notable amplitude variability
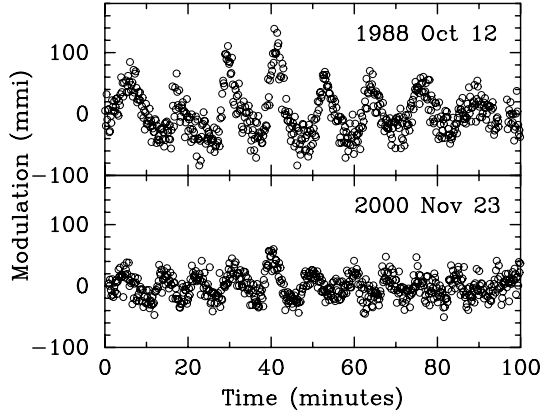
Figure 2. Upper panel: the discovery light curve of KUV 05134+2605. Lower panel: one of the light curves acquired during the WET run on the star. Note the change in the pulsational time-scales and amplitudes.
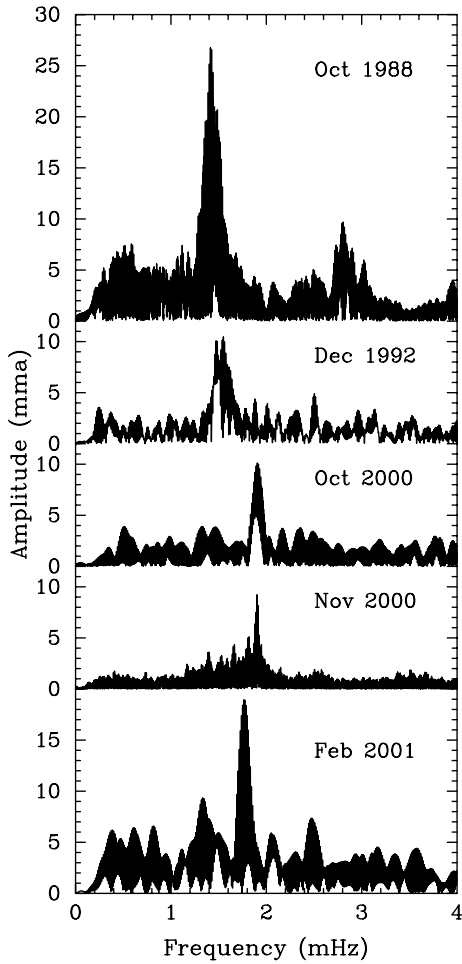

Figure 3. Amplitude spectra of all available measurements of KUV 05134+2605. The frequencies and amplitudes of the dominant signals are different in almost every data set.

Table 3. Dominant signals in the light curves of KUV 05134+2605 in our data. The error estimates in the periods include alias ambiguities, and amplitudes are listed for completeness.

Month/Year	Period (s)	Amplitude (mma)
Oct 1988	707 ± 6	25
	665 ± 7	16
	777 ± 8	10
Dec 1992	645 ± 9	10
	678 ± 11	9
Oct 2000	525 ± 7	9
Nov 2000	526 ± 3	9
	556 ± 4	4
	600 ± 4	4
	716 ± 5	3
Feb 2001	567 ± 8	18
	757 ± 14	8

Of course, all the data sets are affected by aliasing and no definite periods can be determined, but approximate periods in the different regions of power in the Fourier spectra that are separated by more than the width of the envelope of the corresponding spectral window, can be estimated. We summarize these results, omitting possible combination frequencies, in Table 3. The amplitudes in this table must be taken with some caution, as they could be affected by insufficient frequency resolution in some of the data sets.

As already noted, there is no correspondence between the period of the dominant modes in each of the subsets of data except for the two closest in time (2000 October/November). It almost appears that we looked at a different star every time KUV 05134+2605 was observed!

In any case, we tried to find the signatures of non-radial gravity (g)-mode pulsations from Table 3, also with the help of Fig. 4, where we plot the detected periods over the different observing seasons. However, equally spaced periods suggestive of the presence of a number of radial overtones of the same ℓ or equally spaced frequencies that might be due to rotational *m*-mode splitting were not detected.

We can therefore summarize the frequency analysis of KUV 05134+2605 as follows: it has a very rich mode spectrum and its pulsation amplitudes are highly variable. We cannot find a stable pulsational signal which would allow us to estimate an evolutionary period change. Only a dedicated multisite campaign would help to understand this star.

3.2 PG 1654+160

We again start the frequency analysis with the WET measurements. The spectral window and amplitude spectrum of these data are shown in Fig. 5. Although the amplitude spectrum does not appear very complicated, attempts to determine the underlying variations by prewhitening result in a large number of signals that seem to be present.

However, assuming that we deal with normal-mode pulsations of the star, the number of signals becomes unrealistically large, and some of the frequencies found that way are too closely spaced to be resolved within our data set. All this suggests that the amplitude spectrum of PG 1654+160 was not stable throughout the observations.

Consequently, we attempted to follow the suspected amplitude and frequency variability throughout the data set with various
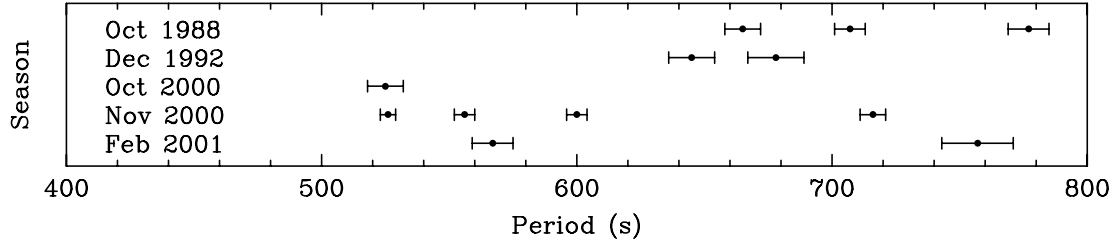
on time-scales as short as 6 weeks. We cannot make any statement about frequency/phase variability as our data sets are too small to distinguish this hypothesis from the effects of beating between several signals.

We can attempt to construct the complete mode spectrum of the star by combining the results of the different observing seasons.

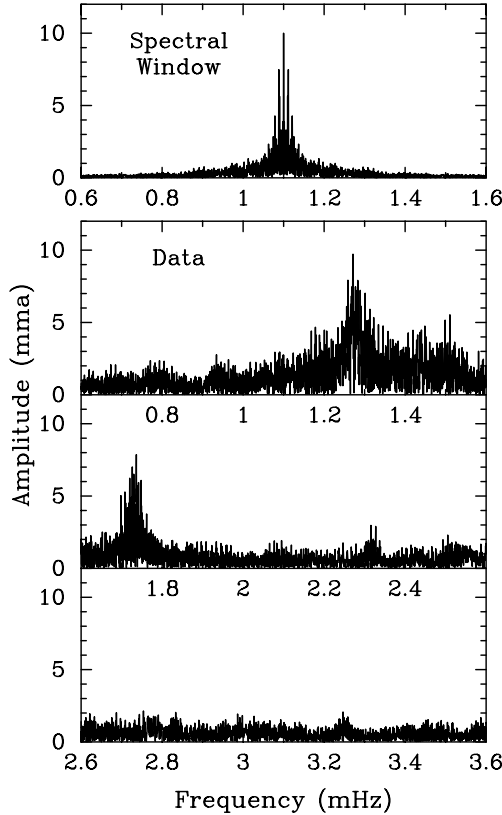**Figure 4.** The variability periods of KUV 05134+2605 as listed in Table 3.

Figure 5. Spectral window and amplitude spectra of the WET measurements of PG 1654+160.

methods but again had to realize that our temporal coverage is insufficient for a detailed analysis. Some results can however be obtained.

(i) The longer period pulsations ($P \gtrsim 700$ s) show a larger degree of instability.

(ii) The amplitude spectrum was more stable during the second part of the run (beginning with April 25).

(iii) Amplitude variability alone is insufficient to account for the observed variations; the pulsation frequencies also appear somewhat variable.

(iv) The periods of the strongest signals can be determined, albeit with large errors due to the instability and aliasing.

The periods we could determine are listed in Table 4, together with the results from the other data sets to which we now turn.

In the same fashion as in the previous section, we computed amplitude spectra of all our data sets over the years. We show them in Fig. 6 which demonstrates that the pulsational behaviour of PG 1654+160 is also highly variable in time; a comparison of light curves is shown in Fig. 7. The time-scales of the amplitude vari-

Table 4. Dominant signals in our light curves of PG 1654+160. The error estimates in the periods include alias ambiguities, and amplitudes are listed for completeness.

Month/Year	Period (s)	Amplitude (mma)
Aug 1983	577 ± 6	24
	842 ± 13	15
June 1985	777:	14
	756:	11
	705 ± 6	10
	878 ± 8	10
	817 ± 7	8
	656 ± 5	6
Apr 1994	927 ± 10	31
	854 ± 16	12
Apr/May 2001 (WET)	781 ± 6	10
	579 ± 3	8
	662.0 ± 0.5	5
	700 ± 1	4
	833 ± 4	4
	431 ± 1	3
May 2001	791 ± 15	21
	575 ± 6	20
	913 ± 15	19
June 2001	697 ± 5	19
	658 ± 5	12

ations of PG 1654+160 can be as short as two weeks: the strong 913-s signal in the May 2001 data was absent in the previous WET data.

We determined the dominant periods in the different data sets, and summarize them in Table 4. Again, the amplitudes may be affected by resolution problems, and possible combination frequencies were excluded. In addition, there is good evidence for more signals being present in several of the data sets, but it is not possible to determine their periods and amplitudes reliably.

Some comments are necessary: the two strongest modes in the single-night data set from 1985 June are not resolved, which is why we cannot determine error estimates for their periods and thus disregard them for the following analysis. The errors on the other frequencies in this data set were assumed to be $1/4T$, where T is the length of the run. For the other data sets, the errors on the periods include some possible alias ambiguities. In the 1994 April data, the $2f$ harmonic of the dominant periodicity is also present. We therefore used the residualgram method (as described before) with $M = 2$ to obtain a more reliable determination of this period before searching for more signals.

It is interesting to note that some periodicities in Table 4 occur in more than one data set. We have displayed these results graphically in Fig. 8, where we again show the detected periods over the different observing seasons. We note that the shorter periods ($P <$
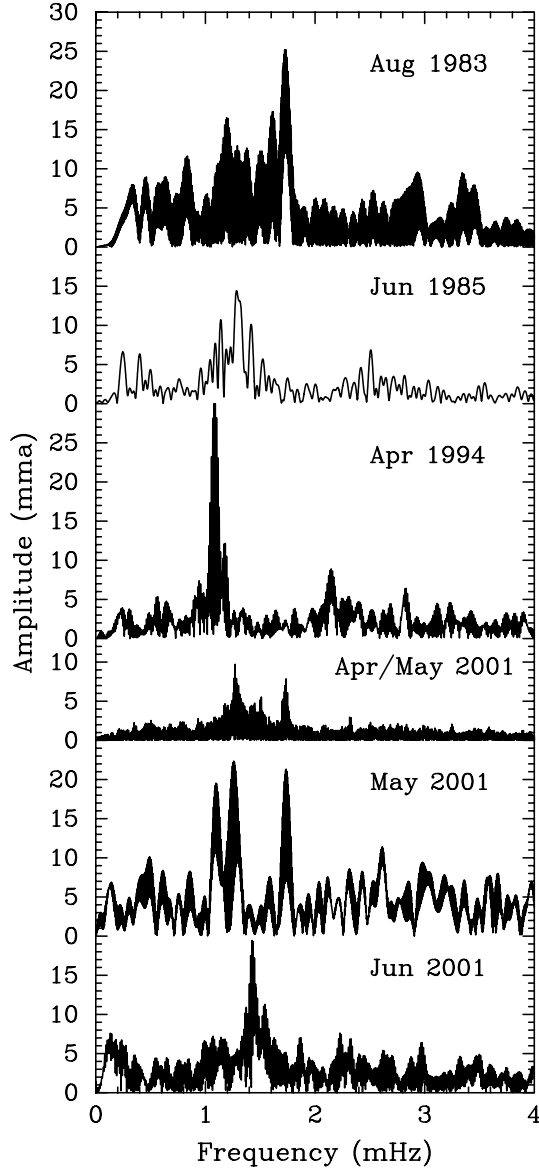
Figure 6. Amplitude spectra of all available measurements of PG 1654+160. This star also shows conspicuous amplitude variability.
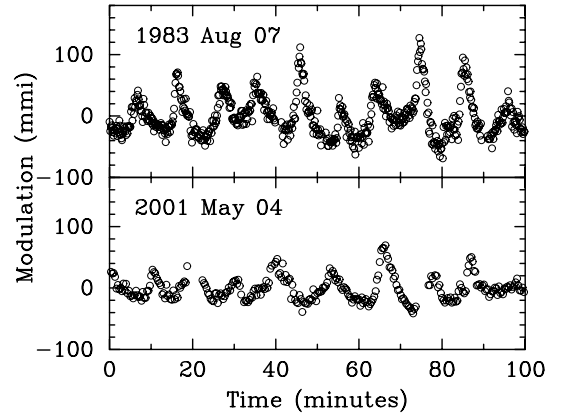

Figure 7. Upper panel: the discovery light curve of PG 1654+160. Lower panel: one of the light curves acquired during the WET run on the star. Again, the pulsational time-scales and amplitudes changed considerably.

of a normal-mass ($\approx$0.6 M$_\odot$) DBV white dwarf pulsating in $\ell = 1$ modes (see, e.g. Bradley, Winget & Wood 1993).

A comparison of the individual mode periods of the known $\ell = 1$ pulsator GD 358 (Winget et al. 1994; Vuille et al. 2000) and those of another DBV, CBS 114 (Handler et al. 2002), with that of PG 1654+160 also supports this interpretation. However, the number of available observed modes of PG 1654+160 is insufficient for seismic model calculations, and the uncertainties of their periods are too large.

What may be the cause of the amplitude (and possibly also frequency) variability in the two stars? As neither has been reported to be magnetic in the literature, interaction between the different pulsation modes remains the most promising hypothesis for an explanation.

In this case, the time-scale of the amplitude variability is expected to be of the order of the inverse growth rates of the affected modes. Growth rates are not very well known for pulsating white dwarfs, but it is clear that longer-period modes have larger growth rates than shorter-period ones. Detailed growth-rate calculations (Dolez & Vauclair 1981) imply that amplitude variability may occur on time-scales down to about one week.

These theoretical predictions are consistent with our observations, at least as far as we can tell. The longer-period modes of PG 1654+160 indeed seem to vary more rapidly in amplitude than the ones at shorter period [it is interesting to note that Kepler et al. (2003) made the same observation for GD 358], as implied by our attempts to trace these variations. The time-scale of the amplitude variability of both stars also appears to be of the expected order of magnitude. However, we must admit that the temporal distribution of our data is such that we can only detect variations on just these time-scales. Hence, the agreement we find can at best be regarded as qualitative.

800 s) in the light curves of PG 1654+160 appear very consistently in the same regions, whereas the longer periods do not show that much regularity. However, the errors in the determination of those periods are also larger. Finally, the previously mentioned shorter-period signals seem to have an approximately equidistant spacing of about 40 s, and again our data show no sufficiently stable modes to estimate the evolutionary period change rate.

4 DISCUSSION

We have shown that the amplitude spectra of both KUV 05134+2605 and PG 1654+160 are variable in time. Whereas we cannot find an underlying pattern in the periods of KUV 05134+2605, the roughly equidistant spacings within the shorter periods of PG 1654+160 suggests the presence of a number of radial overtones of g-modes. The size of this average period separation ($\approx$40 s) is consistent with the expected mean period spacing

5 SUMMARY AND CONCLUSIONS

We have carried out new Whole Earth Telescope measurements of the two pulsating DB white dwarf stars KUV 05134+2605 and PG 1654+160 which were supplemented by single-site data. We also re-analysed all available archival measurements of the two stars.

We showed, for the first time, that both have rich pulsational mode spectra, and that the pulsation amplitudes of both stars are highly
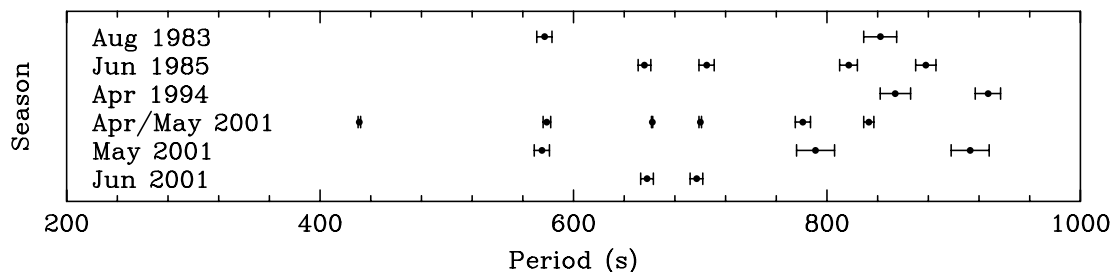
Figure 8. The variability periods of PG 1654+160 as listed in Table 4. Signals with periods below 800 s occur at the same frequencies whenever detected, and they are spaced by integer multiples of about 40 s.

variable in time; PG 1654+160 may show some frequency variability in addition. Beating of multiple pulsation modes cannot explain all our observations, as the observed amplitude and frequency variability is too complex for such an interpretation; hence it must be intrinsic. The pronounced amplitude variations made it impossible to find stable modes to determine the evolutionary period change rates of the two stars.

Whereas there seems no systematic pattern in the periods of KUV 05134+2605 we measured, some of the modes of PG 1654+160 appear at the same periods whenever detected. The spacing of these periods, around 40 s, suggests that they are probably caused by non-radial gravity-mode pulsations of spherical degree $\ell = 1$ in a normal-mass DBV white dwarf.

The amplitude variabilities of both stars could be followed by means of the pre- and post-WET observations that were therefore essential for this work. Their time-scales are consistent with theoretical predictions of resonant mode coupling. This conclusion is however weakened by the temporal distribution of our data, which favour the detection of just those variability time-scales.

Before a more detailed investigation of the amplitude variations of these two stars can be performed (e.g. to guide theoretical work in this direction, Buchler, Goupil & Serre 1995), mode identifications and an improved sampling of the temporal behaviour of the pulsations through continued single-site measurements are desirable. Given the qualitative similarity of PG 1654 and the 'typical' DBV GD 358, we expect that the same nonlinear mode coupling and amplitude modulation mechanisms are at work in both stars. Having very rich mode spectra, both KUV 05134+2605 and PG 1654+160 are also attractive targets for future extensive multisite campaigns.

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