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Results on (un)published WET runs on pulsating DB white dwarfs

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and the Xcov3, Xcov7, Xcov12, Xcov20, Xcov21 and Xcov22 teams

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Abstract.
I have collected all the WET archival data on the pulsating DB white dwarf stars (DBVs) and re-reduced them. In addition, the WET has recently observed three DBVs. Preliminary results on PG 1115+158, PG 1351+489, KUV 05134+2605, PG 1654+160 and PG 1456+103 are presented, and the future use of the data is outlined.

Key words: stars: white dwarfs, oscillations, individual: PG 1115+158, PG 1351+489, KUV 05134+2605, PG 1654+160, PG 1456+103

1. INTRODUCTION

Back in 1994, Todd Watson showed me the results of a student's project he did together with Eric Klumpe, Usama Aziz and Fred Ortiz. They compared the pulsational spectra of the known pulsating DBV white dwarf stars and found some remarkable similarities, just as Clemens (1994) did for the hot DAVs. The latter work ultimately led to mode identifications and ensemble asteroseismology of the DAVs. Whereas Todd et al.'s results on the DBVs were exciting, it was also clear that more observational data were needed to support their conclusions.

Some six years later, I happened to discover a new DBV, PG 2246+121 (Handler 2001). At that time it was, after EC 20058-5234 (Koen et al. 1995), only the second member of its class to show short-period ($P \approx 5$ min), low-amplitude ($A < 0.1$ mag) pulsations.

Although PG 2246+121 had only three independent pulsation modes (split by rotation into altogether 8 components), it was intriguing to see that the periods of these modes were very similar to mode periods of EC 20058-5234.

Obviously, there is more to be learnt from investigations of the mode spectra of the DBVs than the above mentioned phenomenological findings imply at first glance. As the mode spectra of most DBVs appear to be rich, e.g. compared to those of the DAVs, detailed asteroseismological results for individual stars can be expected. In addition, the evolutionary status of the DBVs is highly interesting: firstly, they occur immediately after the DB gap. Knowing the interior structure of a number of DBVs may then tell us about the origin of the DB gap. Secondly, it is unclear whether or not DBs are mostly produced by single-star evolution. DBs originating from binary evolution will have an interior structure different from DBs descending from single stars (Nitta & Winget 1998).

For these reasons (and more), I initiated a systematic program to investigate the pulsational mode spectra of all DBVs in detail. Until a few years ago, such a program was compromised by the faintness of most DBVs (between $B = 15.9$ and $B = 17.2$ except for GD 358 and EC 20058-5234), but with the advent of frame-transfer CCDs for rapid photometry (e.g. see O'Donoghue 1995), this was no longer a real problem.

With the help of the Whole Earth Telescope and other interested colleagues, I collected new photometry of the DBVs and also re-reduced and analysed data from the WET archives that are partly unpublished. The latter part of this program is the subject of this paper. In total, more than 1800 hours of time-series photometry of nine DBVs is now available to me; see Handler (2003) for a detailed data log.

2. WET RUNS ON THE INDIVIDUAL STARS

In the following I will shortly present the results of my analyses. For some stars, the results are not yet definite. I would also like to note that the measurements of EC 20058-5234 taken during Xcov 15 are still being supplemented by single-site observations and are being thoroughly analysed by Denis Sullivan and Steve Kawaler. Consequently, I refer to Sullivan et al. (2003) for this star and will not mention it further.

2.1. PG 1115+158 - Xcov 3 and Xcov 7

PG 1115+158 was a tertiary target during Xcov 3 in 1989 and was observed from La Palma and McDonald; 15 hr of useful observations were obtained. Although the data set is small, it gives an indication of the time scales involved in the pulsations; the multiple periods are around 18 minutes.

The star was re-observed during Xcov 7 in 1992, this time as a secondary target with a Southern-Hemisphere primary. 164 hr of measurement were collected, and a preliminary report on these observations was published by Clemens et al. (1993). Regrettably, not all of the measurements of this star are usable because of its faintness, so that we are left with the data from OHP, CTIO and McDonald (82.4 hr) to perform a frequency analysis. Unfortunately, no conclusive results can be obtained. We show the amplitude spectrum of the whole data set and 4 partitions of it in Fig. 1. The amplitude spectrum of the star is both complicated and temporally unstable; the amplitude variations during the observations cannot be explained by multi-periodic beating alone. A reliable determination of individual frequencies and amplitudes is therefore precluded. Due to the incomplete coverage, it is also not possible to follow the amplitude and possible frequency variability.

If we compare the Fourier spectra of all the available data sets (Fig. 2, including the discovery observations by Winget, Nather & Hill 1987) to look for re-occurring peaks, we also obtain a negative result, even if we cautiously try some prewhitening. It appears that the amplitude spectrum of PG 1115+158 is inherently unstable. The presently available information about its pulsations is insufficient for a seismological analysis. We conclude that only an extensive worldwide campaign with excellent coverage (and CCD detectors due to the long periods) will enable us to understand this star, but even such an attempt could bear the risk of failure.

2.2. PG 1351+489 - Xcov12

This is the only data set I have not completely re-reduced at this point, about half of the 170 hr of measurement still need to be worked on. However, there is a subset of data (4 consecutive nights at the 2.5-m INT) of outstanding quality, and its frequency analysis outlined here is expected to reflect the results of the whole run. We show some prewhitening steps within this data set in Fig. 3.

PG 1351+489 is well known to have a dominant 489-s period (Winget, Nather & Hill 1987) that is also the strongest signal in the

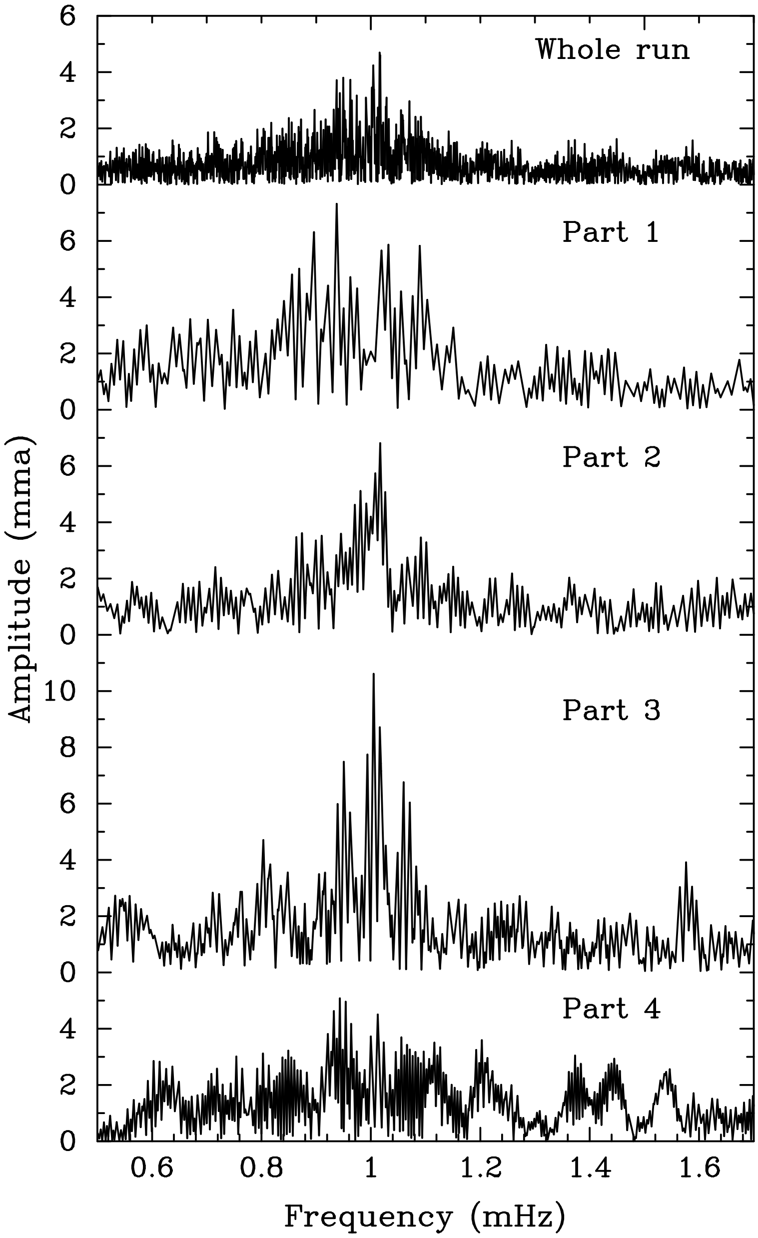

Fig.1. Fourier amplitude spectra of the Xcov7 observations of PG 1115+158. The upper panel is for the whole run; the following ones show four non-overlapping partitions of the data set. Note the strong temporal variability of the amplitude spectrum throughout the run. The amplitude spectrum in frequency regions not shown is consistent with noise.

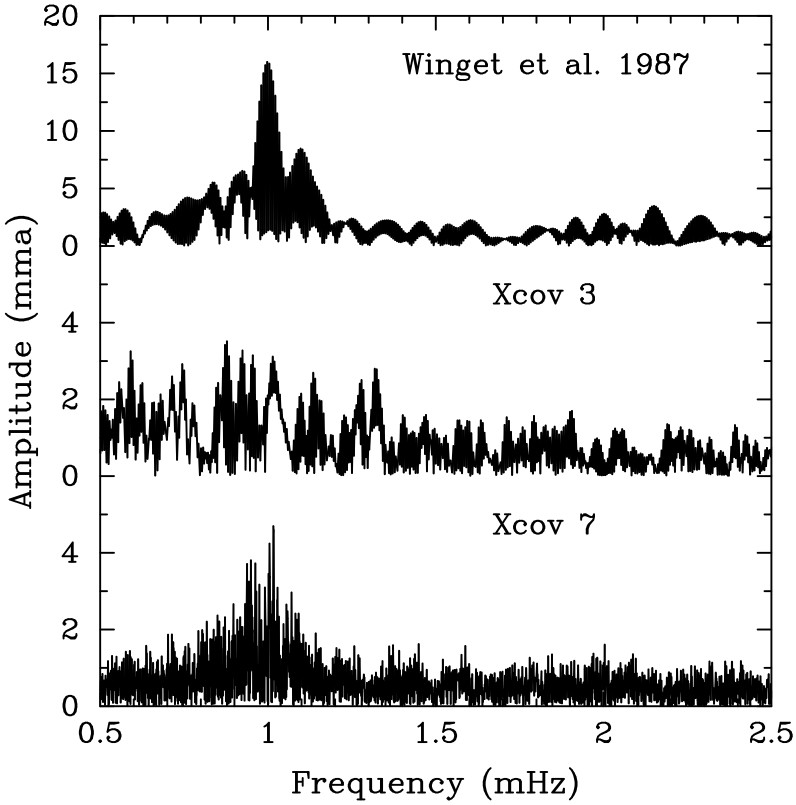

Fig.2. Fourier amplitude spectra of all available measurements of PG 1115+158. The time scales of the variations are always similar, but individual frequencies do not agree even considering aliasing. Note the larger amplitude scale of the uppermost panel.

WET data. In addition, a second signal at 1.46 $\times$ this frequency as well as many harmonic and combination signals are known. All these results are confirmed with the WET data (see Fig. 3).

Some other findings are also interesting: there seems to be a $\approx$ 15μHz splitting within the independent signals and harmonics which may be caused by rotation. Furthermore, a re-analysis of the measurements by Hill (1987) reveals that the dominant frequency is somewhat variable. The time scale of this variation is not yet known, but we hope that the analysis of the total WET data set (which spans two dark-moon periods) will be helpful in this respect. The final frequency analysis of the WET measurements of PG 1351+489 is expected to be difficult, interesting, and rewarding.

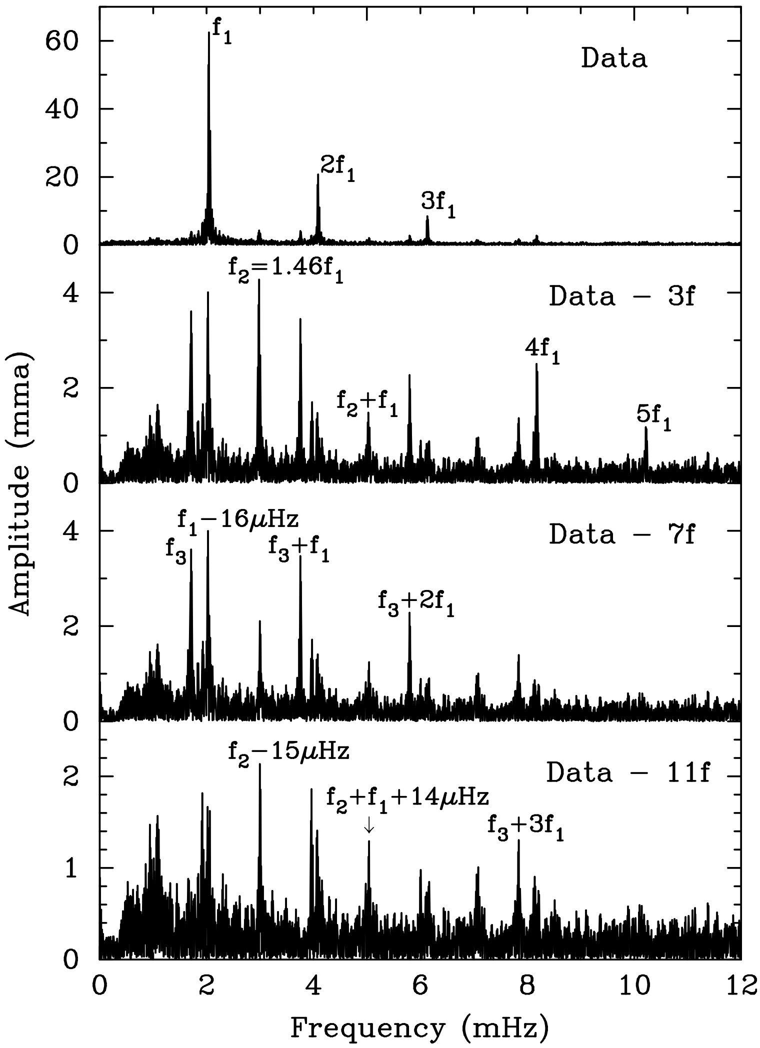

Fig.3. Fourier amplitude spectra of the INT measurements of PG 1351+489. A few independent frequencies with many combination signals are dominant, but many more variations still need to be identified.

2.3. KUV 05134+2605 - Xcov20

This DBV was a secondary target during the WET run in November 2000, and 49 hr of measurement were acquired from the McDonald and SARA observatories. Consequently, this is practically a single-site data set, but it brought two important results: firstly, the amplitude spectrum of the star had changed dramatically since its discovery (Grauer et al. 1989), when it pulsated with time scales of 710 seconds and peak-to-peak amplitudes of 0.2 mag compared to less than 0.1 mag amplitude and a dominant 530-second time scale during the WET run.

Secondly, the pulsation spectrum of the star appears to be very rich. Some trial prewhitening within the WET amplitude spectrum is shown for illustration (Fig. 4.) As opposed to PG 1115+158, the pulsations of KUV 05134+2605 seemed reasonably stable during the run. Therefore, and because KUV 05134+2605 also has a higher surface gravity (thus probably has higher mass) than the other DBVs (Beauchamp et al. 1999), a (non-WET) follow-up multisite campaign was undertaken in December 2001.

2.4. PG 1654+160 - Xcov21

Similar to KUV 05134+2605, PG 1654+160 was also a secondary WET target, but in May 2001. This time the coverage was better, resulting in 81 hours of observations from SARA, Itajuba, CTIO, SAAO, and the NOT in Tenerife.

Regrettably, although the amplitude spectrum of the star (Fig. 5) does not look complicated at first glance, amplitude and frequency variations during the observations were noted. The latter preclude accurate period determinations, but analysis of subsets of data allows at least the extraction of the dominant periods in the light curve. Interestingly, these periods are approximately equally spaced ($\Delta P \approx 40\,\mathrm{s}$). Supported by the spectroscopic surface gravity of the star (Beauchamp et al. 1999), this suggests that PG 1654+160 is a normal-mass ($\approx 0.6 M_\odot$) DBV white dwarf predominantly pulsating with modes of $\ell = 1$.

2.5. PG 1456+103 - Xcov22

This DBV was the primary target of the latest WET run in May 2002. More than 300 hours of measurement were acquired from 16 observatories. It is interesting to note that 10 of these sites, i.e. more than half, used CCD detectors. Both pre- and post-WET data were also collected.

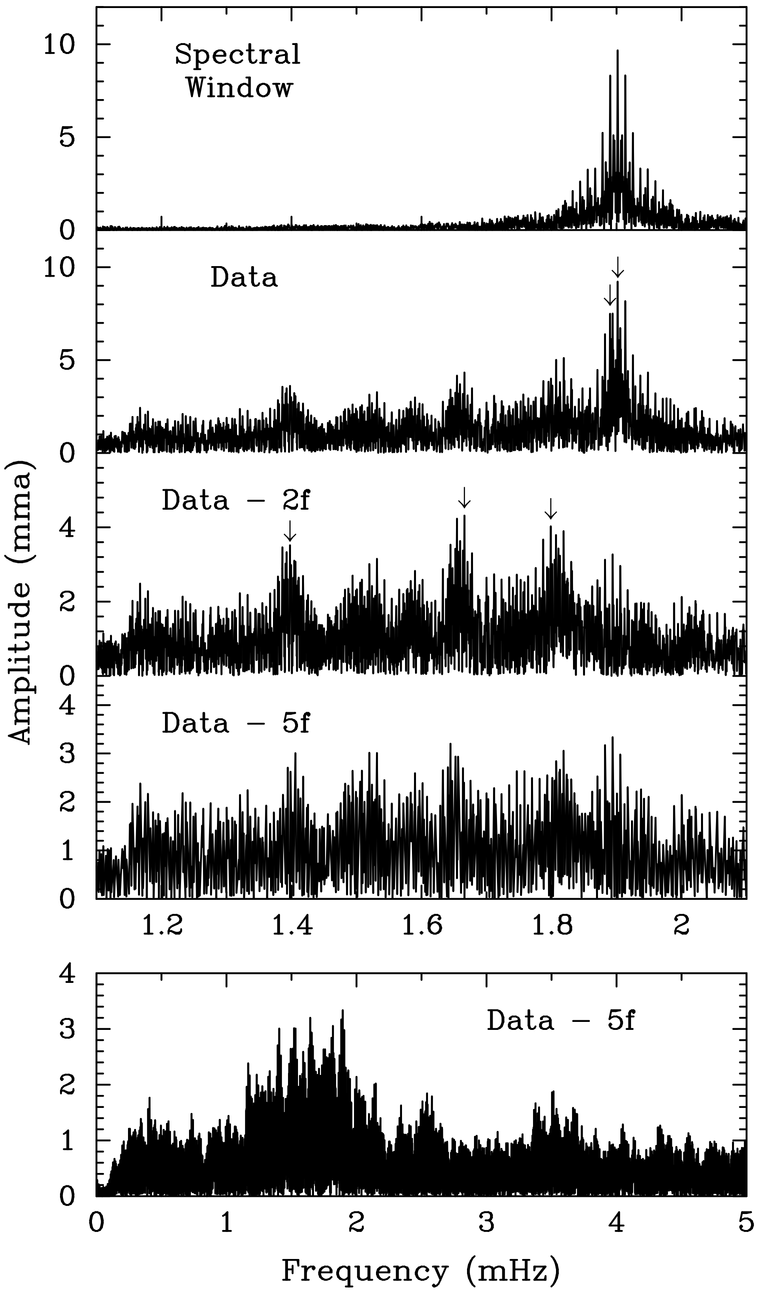

Fig.4. Fourier spectral window and amplitude spectra of the Xcov20 observations of KUV 05134+2605. Some trial prewhitening (of signals indicated with arrows) is shown to demonstrate the richness of the pulsation spectrum. This figure was adapted from Handler et al. (2003).

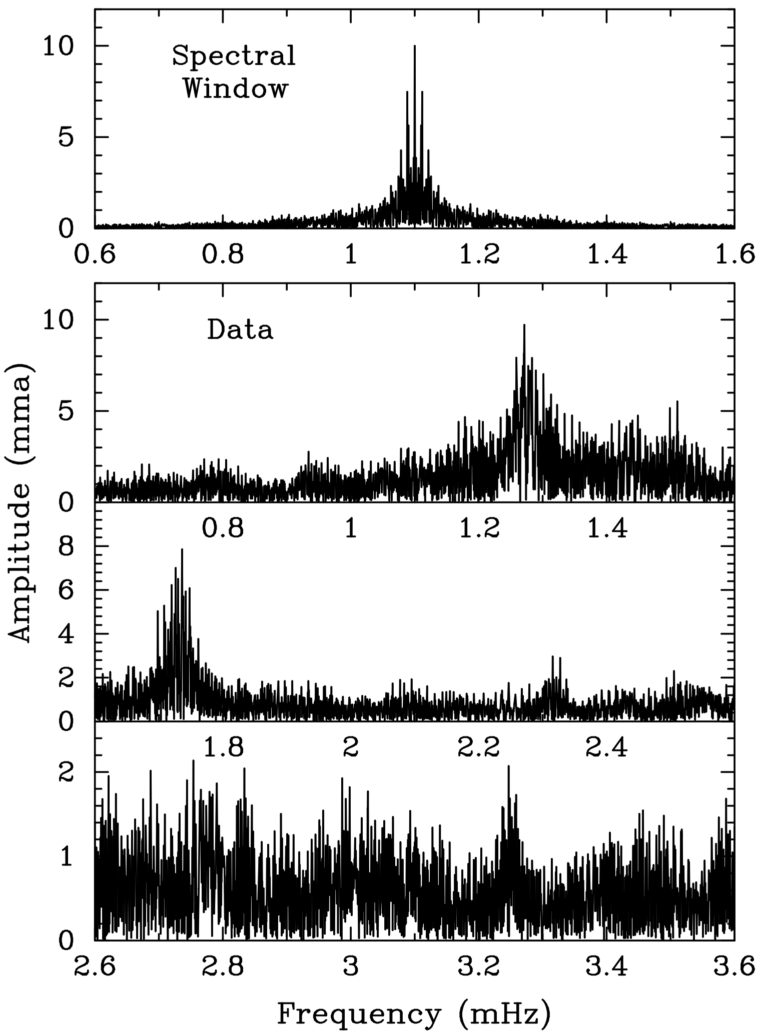

Fig.5. Fourier spectral window and amplitude spectra of the Xcov21 observations of PG 1654+160, adapted from Handler et al. (2003).

Because of the large amount of experimental sites and CCD measurements, the on-line reductions are not complete. Still, some very interesting initial results from the run can be shown. For instance, the star decided to show almost no variability in the pre-WET data (which made the PI quite nervous), but the pulsation amplitudes slowly increased throughout the run and after it, as shown in Fig. 6.

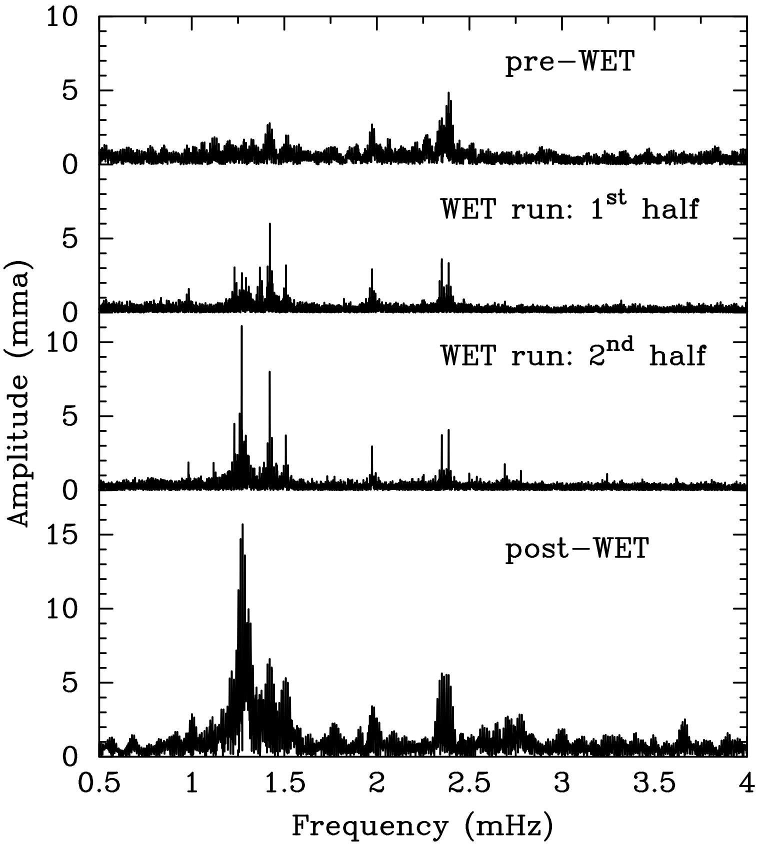

Fig.6. Fourier amplitude spectra of the Xcov22 observations of PG 1456+103, together with those of pre-WET measurements (observer E. Romero-Colmenero at SAAO) and post-WET data (observers M. A. Wood and R. P. Perrine with SARA). This figure is based on on-line reductions and will be superseded.

It is interesting that the amplitude changes only occur at frequencies below 1.8 mHz; the modes between 1.9 and 2.4 mHz remained stable. In addition, combination peaks at frequencies larger than 2.5 mHz also appeared later in the run and during the post-

WET measurements. The WET coverage of the light curve of PG 1456+103 is sufficient to follow the amplitude and frequency variations of the different modes in very detail.

A frequency analysis of the WET measurements reduced on line suggests the presence of at least 12 frequencies in the light curves (a number that is expected to increase after the final reductions and analyses). A frequency spacing of about 20 μHz occurs suspiciously often. An unambiguous mode identification on which asteroseismological modelling of PG 1456+103 can be based seems possible.

3. THE PLAN

The re-analysis of the WET measurements discussed above should ultimately lead to publications in major journals. As not all data sets on the individual stars are sufficient for separate papers, they need to be combined in a useful way.

Consequently, I plan to add the results on PG 1115+158 and PG 1351+489 into one publication, which can be written in the spirit of the discovery paper of these stars (Winget, Nather & Hill 1987). The new WET results can be compared to the original single-site analyses. The data sets on the second-priority targets KUV 05134+2605 and PG 1654+160 can also be combined. As a matter of fact, such a paper has already been written (Handler et al. 2003). Finally, the large data set and anticipated intriguing results on PG 1456+103 warrant an interesting publication by itself.

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