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Preliminary Results in White Dwarf Research by a New Group

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Abstract

A new group, named PiStA, has been established for investigation of white dwarf stars by undergraduate students. Beside a contribution to WET/DARC campaigns, an independent research program has been started. Up to now data collection has been carried out for 5 stars (GD 154, GD 244, KUV 02464+3239, LP 133-144 and G207-9) over a whole observational season for each target.Preliminary results are presented for GD 154. An additional frequency at 213.6 c/d has been identified in an early data set. An alternative interpretation on all available data comparing with a pure multiperiodic pulsation is in progress. Sign of a chaotic behaviour is going to be investigated.

Introduction

Pulsating variable star research has a long tradition in Konkoly Observatory dating back to the early observation of RR Lyraes and δ Cepheids in 1929. Changes in the instrumentation introduced newer and newer fields in the Observatory's profile. As theoretical interpretation of non-radial pulsation developed and the precision of the photoelectric photometry increased, the investigation of low-amplitude, short period, multiperiodic δ Scuti stars, pulsating mostly in non-radial modes, has been started beside the large amplitude, radially pulsating RR Lyraes, δ Cepheids and high amplitude δ Scuti stars (HADS). Paparó joined many international campaigns in the framework of Delta Scuti Network. However, the instrumentation changed again. The 1 m RCC telescope equipped with the CCD camera allowed us the investigation of faint, short period, low amplitude white dwarfs. As a first activity some of the stuff members joined WET campaigns (Handler et al. 2003, Fu et al. 2007). Single site data collection was also urged by some local scientific political reasons. WET/DARC international campaigns have superior results on white dwarfs due to two or three-week long continuous datasets with excellent coverage.

Figure 1: Designed by the team. Light curve of GD 154 is used from our own observation.

The enthusiasm of undergraduate students of Eötvös University on the local, single site observations resulted the establishment of Piszkéstető Students' Astronomy (PiStA) group as a student scientific project (Figure 1). The present members are on masters level. A new generation of PISTA, on even bachelor level, is going to join the group these days. Of course, it takes time to train the students to reach the scientific level and it can be done only step by step as the data processing is going on. Up to now our team (my PhD student, Zsófia Bognár and PiStA) has collected remarkable amount of data for many white dwarfs. We have started the final work on GD 154.

Single-site observation of white dwarf stars

White dwarf research is dominated by a worldwide organization, WET/DARC. When applying for telescope time we have to argue why we need the telescope for concentrated and coordinated observation of a single star. The most important argument is to avoid aliases that are caused by gaps in the data distribution since detection and identification of real pulsation frequencies are much more difficult if aliases are present.

However, there is another fact to be considered. A long light curve is necessary to resolve the closely spaced frequencies in multiperiodic stars. WET/DARC campaigns last no longer than 2-3 weeks. A possible solution is to have two campaigns separated by a short interval (two months for PG 0122+200) to improve the frequency resolution and to get higher precision on the frequencies (Fu et al. 2007). Nevertheless, it is not easy to organize telescopes (especially larger ones) too often to work on the same target. Space projects would be also a solution. According to our knowledge neither the running nor forthcoming space projects will observe white dwarf stars.

Single-site monitoring of white dwarfs is still worthwhile. We can follow their pulsational behaviour not in a continuous dataset but on a long time base. We can have a sample of temporal characteristics from month to month up to 5-6 month if the target is properly chosen in declination. We can always use the best part of the sky. Of course, we are faced with the problem of side-lobes and with a beating of closely spaced frequencies over shorter datasets. However, careful comparative analyses can help to come over part of the problem.

It has become clear in the last years that amplitude and frequency variations are common amongst pulsating stars. White dwarfs are not exceptional in this respect either. Although, some of the modes are extremely stable and the period increase and decrease can be measured, the amplitude variability and in some cases the frequency variability are well-established (down to two weeks, Handler et al. 2003). The aim of our "continuous" single-site observational project is to follow the short-term variability of pulsation in white dwarfs. Of course, we will join the WET/DARC campaigns from time to time.

Observed targets

We used different guidelines in target selection. The main aim was to keep up the enthusiasm of the young group. GD 154, the first target, was suggested by Gilles Fontaine for educational purposes. The star has short periods and large amplitudes. The aim was fulfilled. The students were delighted from the first moment by the impressive light variation of GD 154. We later followed more practical and more scentifical guidelines as criteria. We always wanted to use the best part of our sky. Regarding the faintness of white dwarfs and the size of our telescope, we had to pay attention to this point. We usually picked the newly discovered stars with coordinates proper to our site.

Table 1 gives the number of clear nights over the given interval. Each target was observed in the whole observational season, as often as we got telescope time at our mountain station at Piszkéstető. The observations were carried out by a Roper Scientific 1300B CCD camera (20*20 μm, 1340x1300 pixel) with a 7'x7' field of view. In each cases we observed in white light to have as many counts as possible. Ten or 30 seconds exposure time, depending on the quality of the sky, were used. In average, we used approximately 50% of the telescope time allocated to our targets, which is not a bad ratio.

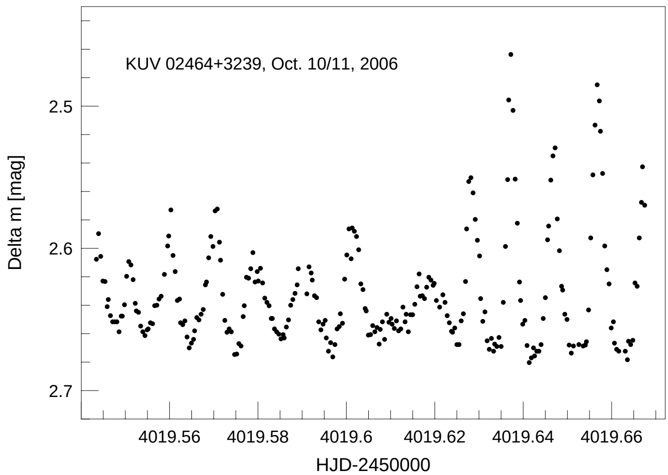

Figure 2: KUV 02464+3239 has large amplitude, long period. It is located near the red edge of DAV instability strip.

Table 1: Targets observed in 2006-2007 by PiStA.

Star	**No. of nights**	**Interval**
GD 154	20	Febr. - July 2006
GD 244	14	July - Oct. 2006
KUV 02464+3239	19	Oct. 2006 - Febr. 2007
LP 133-144	28	Jan. - May 2007
G207-9	24	March - Aug. 2007

A sample of the light curves obtained for our targets are presented. A typical part of the light curve of KUV 02464+3239 is given in Figure 2. It has a large amplitude and a long period in agreement with its location near the red edge of the DAV empirical instability strip. A preliminary analysis of part of the presently available data was presented by Zs. Bognár et al. (2007). Even in the preliminary analyses of a short dataset three additional frequencies were obtained. The final analysis of KUV 02464+3239 is in progress.

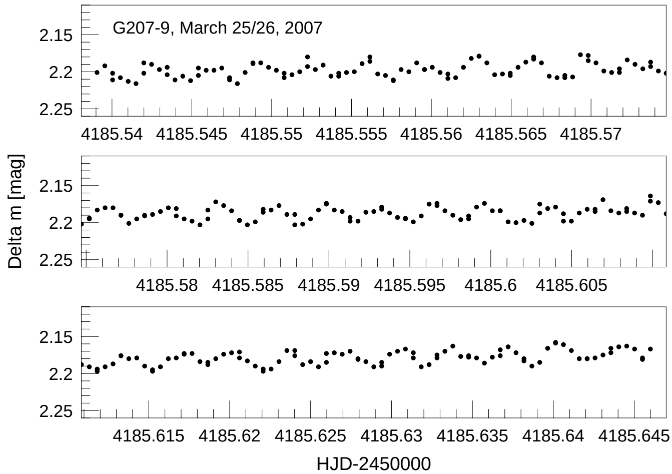

Figure 3: High presision measurements allowed us to follow the low amplitude and short period of G207-9.

Figure 3 shows a sample of the light curve of the DA white dwarf, G207-9. It has much lower amplitude than KUV 02464+3239. Our precision is still good enough to follow the short period and low amplitude single cycles.

LP 133-144 has been recently discovered (Bergeron & Fontaine 2004). The discovery paper shows a rather irregular light curve just as our observations (Figure 4). As they stated, the relatively short period and low amplitude are consistent with the star's location near the blue edge of the ZZ Ceti instability strip.

According to the first detection, GD 244 is an intermediate-amplitude pulsator with periods which are consistent with its position in the middle of the ZZ Ceti instability strip (Figure 5). It appears to be a photometric clone of GD 66. As a result of this WET/DARC workshop, a collaboration was established. F. Mullally allowed us to work on his unpublished data of GD 244 (2003 - 2006). Our team obtained data for GD 66 in a multisite, coordinated run (October-November 2007).

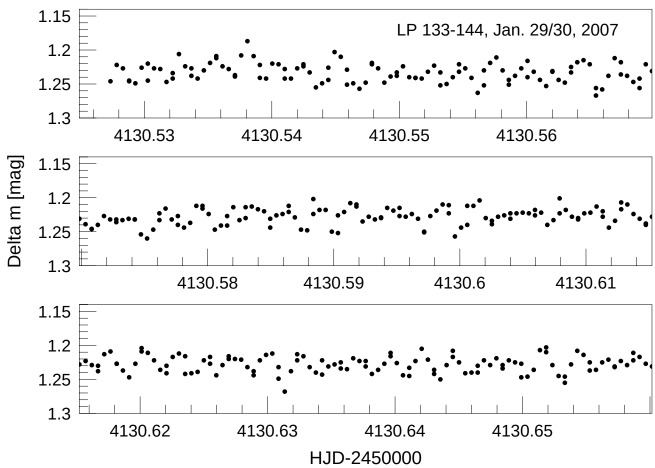

Figure 4: LP 133-144 has an irregular light curve like in the discovery paper. It is near the blue edge of DAV instability strip.

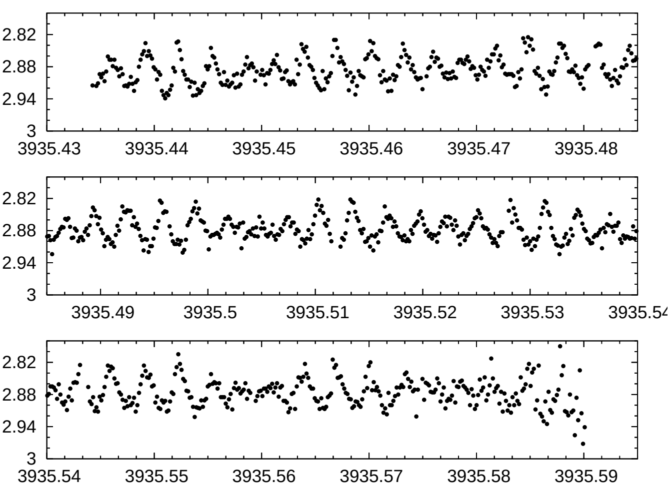

Figure 5: GD 244 is an intermediate-amplitude pulsator located in the middle of the DAV instability strip.

Preliminary results on GD 154

GD 154 belongs to one of the best studied DAV white dwarfs ($T_{eff} = 11180/$,K, log g = 8.15, M_v=15.33, M=0.7$M_\odot$). It was discovered in 1977 (Robinson et al. 1978). Observations were obtained on ten nights (23.5 hours) over two months. Probably the abrupt change in the rather regular light variation made the star interesting enough to have it as a WET target in 1991 (Pfeiffer et al. 1996). In the WET campaign 162.5 hours data was collected in two weeks from 6 observatories. A shorter run (62 hours over 12 nights) was carried out in 2004 from two sites (Hürkal et al. 2005).

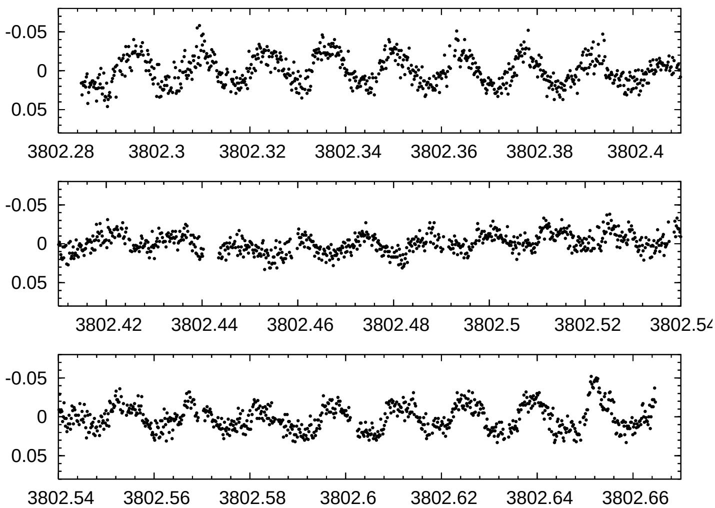

Figure 6: Light curve of GD 154 with 10 s exposure time.

Observation of GD 154 was carried out at Piszkéstető, the mountain station of Konkoly Observatory, from February to July in 2006. To have an impression of the quality, a single night data is shown in Figure 6. Altogether 90 hours data was collected over 20 nights, using 16315 CCD frames. If we compare with the previously obtained datasets, our dataset is not as long and the distribution is not as compact as the others, but it covers a much longer interval of the star's pulsational behaviour.

In data reduction the IRAF package was used but not in a direct command mode. To avoid any personal mistake and to speed up the process a Perl script was used for the reduction. Final data processing, especially the correction for colour effects, is going to be finished for the end of 2007. Regarding the B-V = 0.19 value of GD 154, we found that the B-V values of the potential comparison stars on the field are rather different (from 0.59 to 1.37). These values are converted from the SDSS colours. Careful colour correction is needed.

We are planning to have a comparative analysis for all available data, however, to have the previous data in final form proves not to be a trivial task. The raw data was kindly put at our disposal by Robinson and Kawaler. New reduction has been finished (data from 1977) or is almost finished (data from 1991), respectively.

To get a homogeneous aspect of the star's pulsational behaviour we started the independent analyses of datasets divided by many years. Obviously we started with the earliest dataset. The dominant feature of the light curve are shown in Figure 7. Most of the time they seem to have a single period. Deviation from a single sine wave suggests the presence of the harmonics, too. However, the most remarkable feature is the alternately lower and higher amplitude value of the consecutive cycles. It is similar to the period doubling bifurcation that happens on the way to the chaotic pulsation. Subharmonics of the frequencies are also expected.

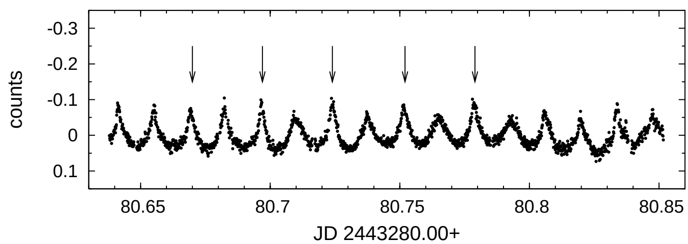

Figure 7: A typical part of the light curve of GD 154 in 1977.

Of course, the result of our Fourier analyses (Table 2) confirmed the previous statements. In agreement with Robinson et al. (1978) we found the dominant frequency at 72.83 c/d. Harmonics up to $6F_1$ are also significant. Subharmonics, not only at $1.52F_1$ but its harmonics at $2.52F_1$, are also above the significance level. The peak at $3.52F_1$ has just a little lower significance value than the significance level. Subharmonic at $1.52F_1$ was interpreted by them as an independent frequency. This view was highly supported by the fact that this was the dominant mode on the last night of their observational run (the light curve had completely changed).

As a new result, we localized a second independent frequency at 213.61 c/d, which is near the $3F_1$ value (218.51 c/d). It is confirmed by the significance value. In the paper of Robinson et al. (1978) the Fourier spectrum of a single night is shown, to present the harmonics and subharmonics. We used the whole dataset in our analyses, except the drastically different last night.

Table 2: Pulsation modes observed in GD 154.

	Frequency	**Amplitude**	**S/N**
F1	72.8381 ± 0.0001	0.0334 ± 0.0002	38.30
2 F1	145.6762 ± 0.0004	0.0114 ± 0.0002	18.87
3 F1	218.5142 ± 0.0007	0.0060 ± 0.0002	11.70
4 F1	291.352 ± 0.001	0.0038 ± 0.0002	8.23
5 F1	364.190 ± 0.002	0.0024 ± 0.0002	6.61
6 F1	437.028 ± 0.003	0.0013 ± 0.0002	4.05
1.52 F1	110.7449 ± 0.0008	0.0052 ± 0.0002	7.40
2.52 F1	183.588 ± 0.002	0.0026 ± 0.0002	4.80
F2	213.610 ± 0.002	0.0025 ± 0.0002	4.91
$\sim$ *F1*	74.211 ± 0.001	0.0038 ± 0.0002	4.36
3.52 F1	256.455 ± 0.002	0.0017 ± 0.0002	3.73

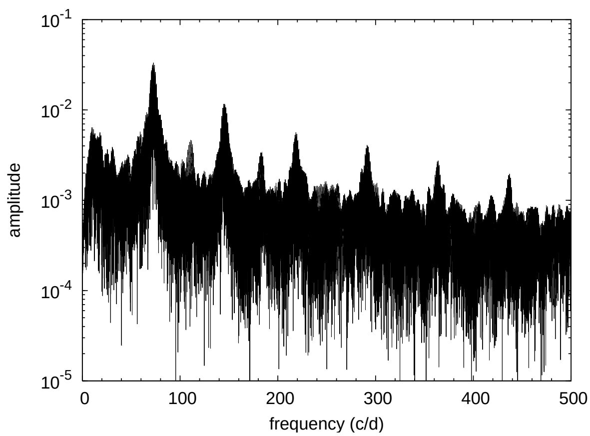

Figure 8: Harmonics and subharmonics are clearly seen.

The second frequency is not a new one, it was found in the WET dataset (Pfeiffer et al. 1996). As the subharmonics appear more clearly on the logarithmic scale, it is shown in Figure 8. The two subharmonics are clearly seen but the $0.5F_1$ subharmonic is missing. Subharmonics were not found in the compact dataset of WET campaign in 1991. Only three independent frequencies and their linear combinations were identified. However, even in the preliminary analyses of our dataset obtained in 2006, we also found a sign of subharmonics.

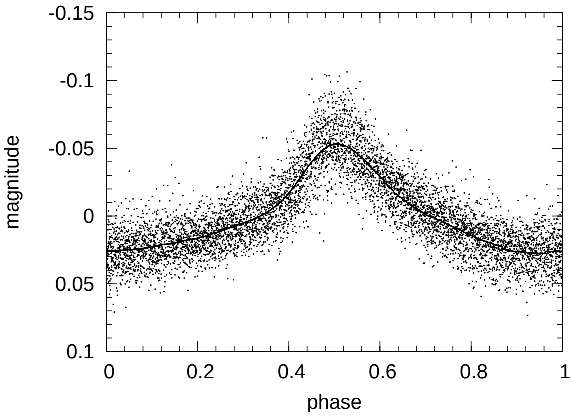

Figure 9: Folded light curve of GD 154.

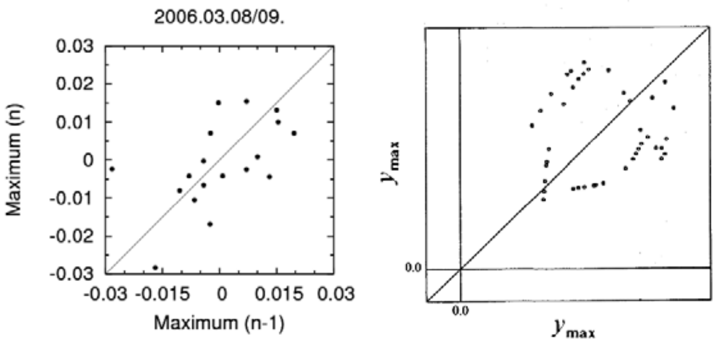

Figure 10: Empirical return map of GD 154 (left) and a theoretical one of a pure chaotic system (right).

As a first step of the nonlinear investigation planned for all available data, the folded light curve of GD 154 using data from 1977 is given in Figure 9. Maybe, it is unusual in the white dwarf's investigation but it is widely used for RR Lyrae stars, to get information on the systematic cycle to cycle variation, like Blazhko effect. It is a basic step to build up the return map, i.e. the plot of the values of the consecutive maxima versus those of the previous maxima. This is the simplest method where the chaotic behaviour can be investigated. Return maps are shown in Figure 10. The left panel shows a return map based on our single night observation. Return map of pure chaotic system by Saitou et al. (1989) is given in the right panel. A similarity of the empirical return maps of GD 154 to a pure chaotic system suggests that it is worthwhile to investigate in details. We will report on the more sophisticated investigation of the chaotic behaviour of our final data in a next paper. Chaotic behaviour has been investigated in white dwarfs (Goupil et al. 1988) but a pure period doubling bifurcation has never been definitely proved in any case. GD 154 is a promising candidate.

Conclusion

The continuous single-site monitoring seems to be worthwhile in characterizing the temporal pulsational behaviour of white dwarfs. It is an excellent scientific project for students providing them with their master or PhD thesis. What is more, they can obtain high level scientific results.

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M. Paparo, S. O. Kepler and G. Vauclair discuss the last talk.