

A Progress Report on the Empirical Determination of the ZZ Ceti Instability Strip

A. Gianninas, P. Bergeron, and G. Fontaine

Département de Physique, Université de Montréal, C.P. 6128, Succ. Centre-Ville, Montréal, Québec, Canada, H3C 3J7

Abstract. Although the Sloan Digital Sky Survey has permitted the discovery of an increasing number of new ZZ Ceti stars, recent published analyses have shown that there are still many relatively bright (V < 17) ZZ Ceti stars waiting to be found. We will discuss the discovery of several such objects in addition to a number of DA stars in which we detected no photometric variations. These were uncovered as part of an ongoing spectroscopic survey of DA white dwarfs from the McCook & Sion Catalog. By determining the atmospheric parameters of a large sample of DA stars, we were able to identify objects placed within or near the empirical boundaries of the ZZ Ceti instability strip. By establishing the photometric status of these stars, we can use them in an effort to conclusively pin down the empirical boundaries of the ZZ Ceti instability strip.

1. Ongoing Survey of the McCook & Sion Catalog

Since the early 1990s, our group in Montreal has been carrying out a systematic study aimed at defining the empirical boundaries of the ZZ Ceti instability strip. We use quantitative time-averaged optical spectroscopy to pin down the locations of candidate stars in the $T_{\text{eff}}$-$\log g$ plane, and we follow up on these candidates with “white light” fast photometry to determine whether a target pulsates or not. The determination of these boundaries is essential if we are to understand the ZZ Ceti phenomenon as a whole. The question of the purity of the instability strip is also an important issue for several reasons. First, a pure strip implies that ZZ Ceti stars represent an evolutionary phase through which all DA white dwarfs must pass. It is then possible to apply what is learned from asteroseismological studies of these stars to the entire class of DA white dwarfs. Second, knowing the strip is pure allows us to predict the variability of stars that lie within its boundaries.

In the last few years, we have undertaken a spectroscopic survey of a subsample of DA white dwarfs from the Catalog of Spectroscopically Identified White Dwarfs of McCook & Sion (1999). We thus obtain optical spectra for each star and by fitting the Balmer line profiles using a grid of synthetic spectra generated from detailed model atmospheres we can accurately measure $T_{\text{eff}}$ and $\log g$ for each star. It is then possible to identify white dwarfs whose atmospheric parameters place them near or within the ZZ Ceti instability strip. We will discuss here the latest results of this ongoing effort. Indeed, despite the Sloan Digital Sky Survey permitting the discovery of a plethora of new ZZ Ceti stars, there are still relatively bright (V < 17) ZZ Ceti stars to be discovered as we and others (Silvotti et al. 2005; Voss et al. 2006) are finding out.
Figure 1. (a) Light curves of the 6 new ZZ Ceti stars listed in Table 1. Each point represents a sampling time of 10 s. The light curves are expressed in terms of residual amplitude relative to the mean brightness of the star. (b) Fourier (amplitude) spectra for the light curves of the 6 new ZZ Ceti stars in the 0-10 mHz bandpass. The spectrum in the region from 10 mHz to the Nyquist frequency is entirely consistent with noise and is not shown. The amplitude axis is expressed in terms of the percentage variations about the mean brightness of the star.
Table 1. Photometric parameters of the six new ZZ Ceti white dwarfs

| WD    | Name        | V (%) | Amplitude (%) | Dominant Period (s) |
|-------|-------------|-------|---------------|---------------------|
| 0036+312 | G132-12    | 16.20 | 0.43          | 212.7              |
| 1150−153 | EC 11507−1519 | 16.00 | 0.77          | 249.6              |
| 2148−291 | MCT 2148−2911 | 16.10 | 1.26          | 260.8              |

| WD    | Name        | V (%) | Amplitude (%) | Dominant Period (s) |
|-------|-------------|-------|---------------|---------------------|
| 0016−258 | MCT 0016−2553 | 16.10 | 0.81          | 1152.4              |
| 0344+073 | KUV 03442+0719 | 16.10 | 0.76          | 1384.9              |
| 2336−079 | GD 1212     | 13.26 | 0.54          | 1160.7              |

2. Photometric Observations & Analysis

We proceeded to secure high-speed photometric measurements for those stars in our spectroscopic survey whose atmospheric parameters placed them inside or near the edges of the known ZZ Ceti instability strip. In all, 6 of these stars turned out to be genuine pulsating DA white dwarfs: ZZ Ceti stars. MCT 2148−2911 was observed through a B-band filter on 2005 August 13 with the 3.6 m Canada-France-Hawaii telescope equipped with LAPOUNE, the portable Montréal three-channel photometer. G132-12, MCT 0016−2553, KUV 03442+0719, and GD 1212 were observed in “white” light during a 5 night run from 2005 October 23 to 27 at the Steward Observatory 2.3 m telescope, equipped once again with LAPOUNE. Finally, EC 11507−1519 (see also Koester & Voss, these proceedings) was observed on 2006 March 22 at Steward Observatory with the same telescope and setup. We also observed another candidate star during this last run, WD 1149+057 (PG 1149+058). Unfortunately, due to increasing cloud cover, our light curve for this object was inconclusive. It was later reported as a new ZZ Ceti star by Voss et al. (2006). Figure 1(a) displays the sky-subtracted, extinction-corrected light curves obtained for each star. The resulting Fourier (amplitude) spectra are shown in Figure 1(b).

Summarized in Table 1 are the data for the 6 new ZZ Ceti stars split into short and long period variables. We list the V magnitude as well as the amplitude and period of the dominant pulsation mode obtained from the corresponding Fourier spectra in Figure 1(b) We note that the periods of the dominant oscillation modes in the first three stars of Table 1 as well as those of the last three objects, are consistent with the positions of these stars inside but near the blue (short-period pulsators) and red (long-period pulsators) edges of the instability strip, respectively. However, as a curiosity, we also point out that the amplitudes of the detected modes in the three “red edge” pulsators are not very large, especially for GD 1212. This goes against the general tendency to observe large amplitudes in the cooler objects. Are we observing stars at the very red edge of the strip, basically “dying off” in amplitude? Note also the very long period seen in KUV 03442+0719, one of the longest if not the longest one ever detected in a ZZ Ceti star (Mukadam et al. 2006).
To obtain proper time-averaged spectra for ZZ Ceti stars, it is necessary to set the exposure time long enough to cover several pulsation cycles. However, the exposure times for the optical spectra of MCT 0016$-2553$, KUV 03442+0719 and GD 1212 are 1800, 1200 and 600 s respectively. By comparing with the dominant periods listed in Table 1, we see that this criterion was not met for these three long-period variables since we did not know a priori that these white dwarfs would turn out to be variable. It will therefore be necessary to acquire new optical spectra for these stars in order to refine our determination of their atmospheric parameters. Consequently, the atmospheric parameters for these objects are considered preliminary (Gianninas et al. 2006).

3. Latest Spectroscopic Results

During an observing run in 2006 April at the Observatoire du mont Mégantic, we were able to secure high signal-to-noise ratio (S/N) optical spectra for a number of the stars reported by Silvotti et al. (2005) and Voss et al. (2006) as either variable or non-variable. We also obtained higher S/N ratio spectra for several ZZ Ceti stars in our sample as well as a properly time-averaged spectrum for the ZZ Ceti star WD 1149+057. The atmospheric parameters we measured for these stars are listed in Table 2 along with the stellar masses and absolute visual magnitudes. Our theoretical framework and fitting technique are

| Name         | $T_{\text{eff}}$ (K) | log $g$ | $M$ ($M_\odot$) | $M_V$ | Note |
|--------------|----------------------|---------|-----------------|------|------|
| New ZZ Ceti  |                      |         |                 |      |      |
| HS 1249+0426 | 12040                | 8.15    | 0.70            | 11.83| 1    |
| HS 1531+7436 | 12920                | 8.45    | 0.90            | 12.18| 1    |
| HS 1625+1231 | 11730                | 8.15    | 0.70            | 11.89| 1    |
| HS 1824+6000 | 11380                | 7.82    | 0.51            | 11.50| 1    |
| New Photometrically Constant |          |         |                 |      |      |
| HS 1253+1033 | 13040                | 7.85    | 0.53            | 11.27| 2    |
| HS 1544+3800 | 13550                | 7.95    | 0.58            | 11.34| 1    |
| HS 1556+1634 | 11972                | 7.44    | 0.35            | 10.89| 1    |
| Revised ZZ Ceti |                |         |                 |      |      |
| WD 1149+057  | 11210                | 8.19    | 0.72            | 12.07| 1,3  |
| WD 1349+552  | 12010                | 7.93    | 0.57            | 11.53| 4    |
| WD 1429−037  | 11370                | 8.08    | 0.67            | 11.87| 2,4  |
| WD 1541+650  | 11640                | 8.18    | 0.72            | 11.95| 4    |

Notes. – (1) Photometric status reported in Voss et al. (2006) (2) Photometric status reported in Silvotti et al. (2005) (3) Time-averaged spectrum (4) Improvement of S/N (S/N > 70)
described at length in Gianninas et al. (2005). In this case, we knew beforehand the photometric nature of our targets and thus we set our exposure times long enough to cover at least 3 pulsation cycles for each star.

We can now update our previous photometric sample (Gianninas et al. 2006) by appending these 4 new ZZ Ceti white dwarfs and 3 photometrically constant DA stars as well as incorporating the revised values of $T_{\text{eff}}$-$\log g$ for the last 4 objects listed in Table 2. Thus, our current view of the empirical ZZ Ceti instability strip is shown in Figure 2. The black open and filled circles represent ZZ Ceti stars and photometrically constant DA stars respectively. The bold open circles are the 6 new ZZ Ceti stars from Table 1. The open triangle is the old position of WD 1149+057 in the $T_{\text{eff}}$-$\log g$ plane, it is connected to its new location by a straight line. The dashed lines represent our empirical determination of the blue and red edges of the instability strip.

It is well known that white dwarfs in this temperature range that are less massive than $\sim 0.475\, M_\odot$ ($\log g \sim 7.75$) must necessarily be the product of binary evolution. This limit is represented by the dashed-dotted line in Figure 2. Indeed, several of the stars which lie above this line have been discovered as being part of unresolved double degenerate systems (Maxted & Marsh 1999; Maxted et al. 2000). In such cases, the atmospheric parameters obtained are an average of the parameters of both components of the system. Thus, the atmospheric parameters for stars that lie above the dashed-dotted line are considered...
very uncertain and they cannot be used to constrain the boundaries of the instability strip. Conversely, HS 1531+7436, now the hottest ZZ Ceti star in our sample, allows us to pin down the location and slope of the blue edge of the ZZ Ceti instability strip. However, more hot ZZ Ceti stars lying near the empirical blue edge are needed in order to firmly establish its location. Furthermore, since the atmospheric parameters for the new long period variables are preliminary, we have refrained from redefining the empirical red edge. We also notice that the atmospheric parameters derived from a properly time-averaged spectrum of WD 1149+057 place it within the confines of our empirical boundaries. We expect the same result once we have secured new spectra for the new long-period ZZ Ceti stars. Finally, we see that the instability strip remains pure, devoid of any photometrically constant stars within its empirical boundaries.

4. Conclusions & Future Work

We have discovered 6 new and relatively bright ZZ Ceti stars and have been able to constrain rather well the empirical boundaries of the ZZ Ceti instability strip. This brings us one step closer to an understanding of the ZZ Ceti phenomenon as a whole but there is still work to be done. Our spectroscopic survey of [McCook & Sion (1999)] is yet to be completed, with ∼ 100 stars for which we still need to acquire spectra. We also need to obtain time-averaged spectra for the long-period variables we discovered. In addition, we want to continue improving the precision of our $T_{\text{eff}}$ and $\log g$ determinations by ensuring that all our spectra have $S/N > 70$. Finally, with the blue and red edges well constrained, we wish to revisit pulsation theory as well as evolutionary models for DA white dwarfs in order to produce the best match between our empirical result and theoretical predictions.

Acknowledgments. We would like to thank the director and staff of Steward Observatory and the Canada-France-Hawaii Telescope for the use of their facilities and for supporting LAPOUNJE as a visitor instrument. We would also like to acknowledge the financial support of the Royal Astronomical Society. This work was supported in part by the NSERC Canada. A. G. acknowledges the contribution of the Canadian Graduate Scholarships. P. B. is a Cottrell Scholar of Research Corporation. G. F. acknowledges the contribution of the Canada Research Chair Program.

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