White Dwarfs as Probes of Fundamental Physics: Tracers of Planetary, Stellar and Galactic Evolution
Proceedings IAU Symposium No. 357, 2019
M. A. Barstow, S. J. Kleinman, J. L. Provencal & L. Ferrario, eds.
doi:10.1017/S1743921320000265

Searching for ZZ Ceti white dwarfs in the Gaia survey

Olivier Vincent, Pierre Bergeron and David Lafrenière

Département de Physique, Université de Montréal, Montréal, Québec, H3T 1J4
emails: ovincent@astro.umontreal.ca, bergeron@astro.umontreal.ca, david@astro.umontreal.ca

Abstract. The Gaia satellite recently released parallax measurements for nearly 400,000 white dwarf stars, allowing for precise measurements of their physical parameters. By combining these parallaxes with Pan-STARRS and CFIS-u photometry, we measured the effective temperatures and surface gravities for all white dwarfs within 100 pc and identified a sample of ZZ Ceti white dwarf candidates within the instability strip. We report the results of a photometric follow-up, currently under way, aimed at identifying new ZZ Ceti stars among this sample using the PESTO camera attached to the 1.6-m telescope at the Mont Mégantic Observatory. Our goal is to verify that ZZ Ceti stars occupy a region in the $\log g$ – $T_{\rm eff}$ plane where no nonvariable stars are found, supporting the idea that ZZ Ceti pulsators represent a phase through which all hydrogen-line (DA) white dwarfs must evolve.

Keywords. white dwarfs, stars: variable, surveys, techniques: photometric

1. Introduction

In recent years, the number of known hydrogen-line pulsating white dwarfs, known as DAV or ZZ Ceti stars, has been growing rapidly. The traditional approach to identify candidates consists in measuring the white dwarf atmospheric parameters, $T_{\rm eff}$ and $\log g$, by fitting the hydrogen Balmer lines, and then to determine whether the object falls within the ZZ Ceti instability strip. The boundaries of this strip have yet to be determined accurately, but they have been empirically shown to be located between 11,000 K $< T_{\rm eff}$ $<$ 13,000 K with a strong dependency on $\log g$ (Green *et al.* 2015). Once a candidate has been identified, variability can be confirmed by measuring its light curve.

The Sloan Digital Sky Survey (SDSS) has shown to be an invaluable source of white dwarf spectra for this purpose, and roughly half of the currently known DAV stars have been found using this survey. Mukadam *et al.* (2004), for instance, have nearly doubled the number of known DAVs at that time, with an impressive discovery of 35 new pulsators. While the spectroscopic approach to finding new ZZ Ceti stars has been very efficient, it is limited by the fact that wide-scale spectroscopic surveys do not focus on white dwarfs, and so the tedious task of finding new candidates falls into the hands of smaller ground-based telescopes. While that may change in the future, a new approach has been provided by the Gaia DR2 parallax measurements along with Pan-STARRS photometry.

The photometric technique relies on observed fluxes averaged over various bandpasses, such as the Pan-STARRS *grizy* magnitudes. These photometric measurements are fitted with synthetic photometry obtained from model atmospheres, with the effective temperature and solid angle $\pi R^2/D^2$ considered free parameters, where R is the stellar radius and D the distance from Earth. Since the distance is known from the parallax measurement, the stellar radius is obtained directly, while the stellar mass and surface gravity can be derived from the mass-radius relation for white dwarfs.

© International Astronomical Union 2020

https://doi.org/10.1017/S1743921320000265 Published online by Cambridge University Press

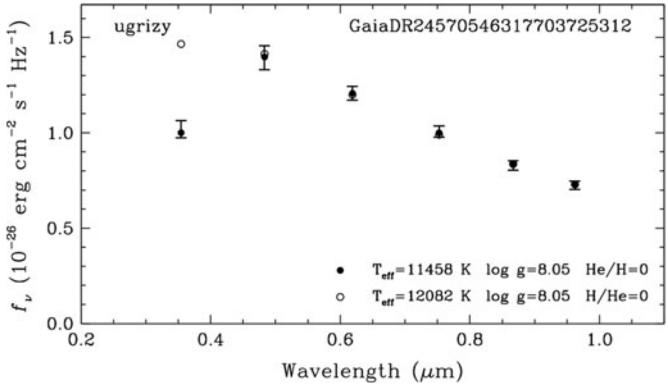

Figure 1. Sample photometric fit to a ZZ Ceti white dwarf candidate using Pan-STARRS *grizy* and CFIS-u photometry (error bars), combined with the Gaia parallax. Filled (open) circles correspond to our best fit under the assumption of a pure hydrogen (pure helium) atmospheric composition. Note that the CFIS-u data point was not used in these fits. The results clearly indicate that this object is a hydrogen-atmosphere white dwarf.

2. Sample Selection

Our initial sample consists of all white dwarf candidates from the Gaia DR2 with $D < 100$ pc and a parallax error less than 10%. This limit on the distance was chosen as to minimize the effects of interstellar reddening. These candidates were then cross-matched with the Pan-STARRS catalog, and all objects were fitted with the photometric technique assuming pure hydrogen atmospheres. We then used the instability strip empirically determined by Green *et al.* (2015) to select our ZZ Ceti candidates in the $\log g - T_{\rm eff}$ plane.

To further reduce the number of false candidates, the u bandpass comes in handy: its wavelength coverage includes the Balmer jump, which is a very distinctive feature between hydrogen- and helium-atmosphere white dwarfs. Indeed, hydrogen-atmosphere white dwarfs show a significant drop in the u-band flux, whereas their helium-atmosphere counterparts show a more continuous flux distribution. Figure 1 shows an example of a photometric fit to one of our ZZ Ceti white dwarf candidates using Pan-STARRS *grizy* combined with the u photometry from the Canada-France Imaging Survey (CFIS; Ibata *et al.* 2017). Here the u magnitude is not used in the fitting but helps to discriminate between the pure hydrogen and pure helium solutions. In the example displayed in Figure 1, we can clearly see the drop in the u-flux caused by the Balmer jump, as correctly predicted by the pure hydrogen model.

It is also worth noting that without the u band, the *grizy* photometry tends to give similar solutions for both hydrogen- and helium-atmosphere models. There are likely many helium-atmosphere white dwarfs polluting our sample, but unfortunately, u magnitudes are only available for a fraction of our sample. On one hand, the SDSS does not cover nearly as much sky as the Gaia survey, and furthermore, the SDSS white dwarf sample has already been investigated extensively for white dwarf pulsators, leaving us with very few new ZZ Ceti candidates. Luckily, the CFIS survey is currently under way, and will eventually provide u-band photometry for many additional targets in our sample. While CFIS will provide data solely for the northern hemisphere, it will cover more sky area than SDSS, and with a much better precision. For a given measurement error, CFIS-u is about 3 magnitudes deeper than SDSS. We have early access to this new survey, and CFIS-u data are being included in our analysis as the data are being released.

https://doi.org/10.1017/S1743921320000265 Published online by Cambridge University Press

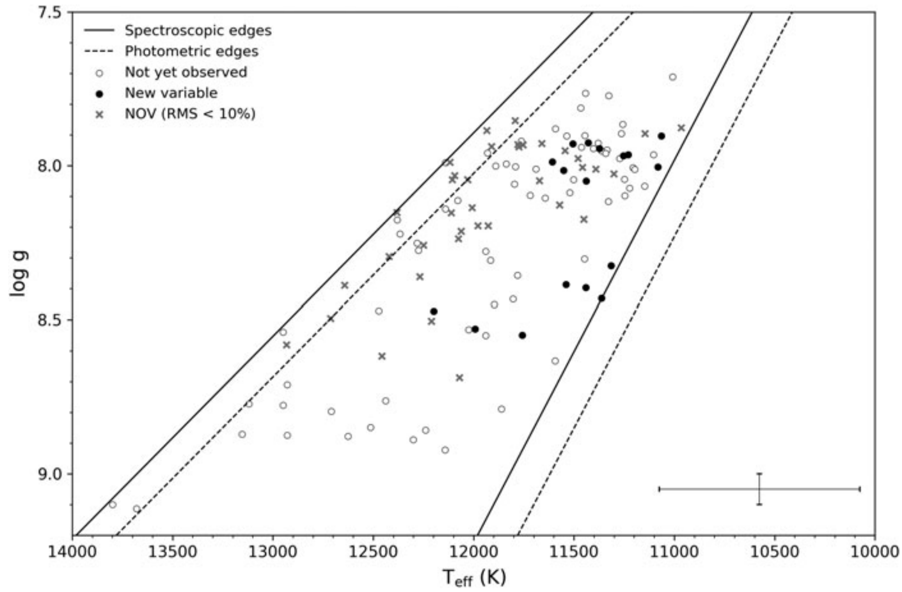

Figure 2. Overview of our photometric survey of ZZ Ceti candidates; the various symbols are described in the legend. The solid lines represent the empirical instability strip inferred from spectroscopy (Green *et al.* 2015), while the dashed lines indicate the same strip shifted by 200 K (see text).

3. Survey Overview

Our survey strategy is to observe as many candidates as possible for two hours using a 10-second exposure time, with a higher priority given to candidates confirmed to be hydrogen-rich through photometric fits including the u bandpass. Our ongoing survey began in late summer 2018 with the Mont Mégantic Observatory 1.6-m telescope equipped with the PESTO instrument, which uses a frame transfer EMCDD to achieve an observing efficiency near 100%. Our final sample contains 134 ZZ Ceti candidates, excluding known variables and objects in the southern hemisphere. Figure 2 shows an overview of the current state of our survey. Each object displayed is a ZZ Ceti candidate, where black filled dots represent new pulsators discovered in our survey, while crosses are objects not observed to vary (NOV), with a photometric error less than 10%.

As of September 2019, 17 new pulsators had been identified. A few selected light curves of these new ZZ Ceti variables are displayed in Figure 3. A wide variety of pulsators has been detected so far. For example, GaiaDR2647899806626643200 is a long-period (∼2000 s) and large amplitude (∼20%) variable, whereas GaiaDR24491980748701631616 has a shorter period of 350 seconds and smaller amplitude of ∼4%. There are also a few pulsators showing multiple pulsation modes, such as GaiaDR24217793816094052480.

Many objects in Figure 2, not observed to vary, are located well within the ZZ Ceti instability strip. While this may appear worrisome at first glance, there are several possible explanations for this result:
(1) The first possibility is the case where the photometric error is larger than the amplitude of the pulsation, in particular at the blue edge of the instability strip. Small amplitude modes can easily be lost within the photometric noise, and it is important to keep this in mind when assessing the variability of an object. Our average photometric error is about 3%, which implies that all pulsators with relative amplitudes close to this value are less likely to be detected in our survey.

https://doi.org/10.1017/S1743921320000265 Published online by Cambridge University Press

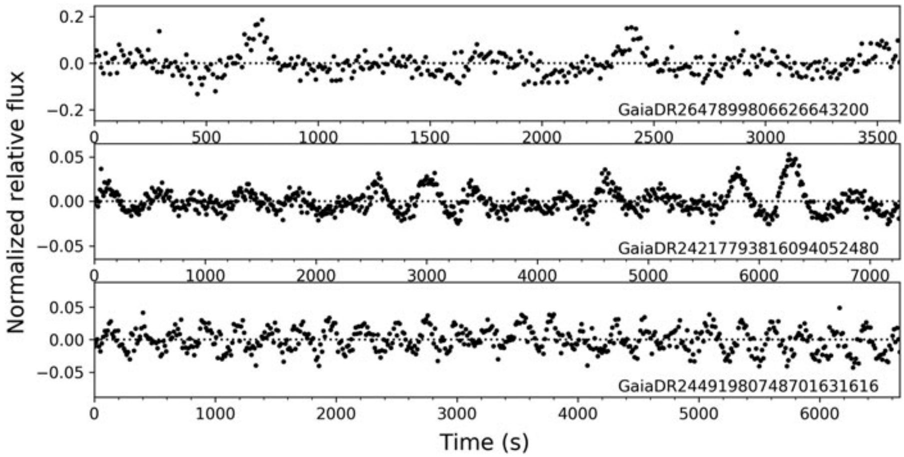

Figure 3. Selected light curves for newly discovered ZZ Ceti white dwarfs.

(2) As mentioned above, we lack u-band photometry for many candidates, and consequently, our sample is most likely polluted by helium-atmosphere white dwarfs. This situation should improve as more CFIS-u photometry becomes available.
(3) There are many cases where the Pan-STARRS magnitudes are contaminated by the presence of an unresolved companion, such as a bright neighbouring star or an M-dwarf. In the latter case, this can be confirmed with infrared photometry. These contaminations may throw off our photometric solutions and misplace the object inside (or outside) the instability strip. We could also be dealing with unresolved double degenerate binaries, which are difficult to identify without spectroscopic measurements.
(4) Systematic differences between the spectroscopic and photometric techniques have been recently reviewed by Bergeron *et al.* (2019). In particular, they found that the photometric technique tends to yield cooler effective temperatures compared to the spectroscopic values when relying on *grizy* photometry alone, and that the inclusion of the SDSS-u magnitude could reduce these differences significantly. Cloutier (2019) found that the photometric temperatures of ZZ Ceti stars based on *grizy* Pan-STARRS magnitudes were 200 K cooler, on average, than the spectroscopic values. Given that our initial selection of ZZ Ceti candidates was based on the empirical strip determined from spectroscopy, we reproduced in Figure 2 the expected photometric instability strip, shifted by 200 K with respect to the spectroscopic values. Many NOV objects near the blue edge are now falling outside of the strip, indicating that hotter ZZ Ceti candidates are more likely to be false positives. Another interesting feature is how the shift puts all the new variables much closer to the middle of the strip, rather than close to the red edge.

References

Bergeron, P., Dufour, P., Fontaine, G. *et al.* 2019, *ApJ*, 876, 67
Cloutier, S. 2018, M.Sc. thesis, Université de Montréal
Green, E. M., Limoges M.-M., Gianninas, A. *et al.* 2015, in Astronomical Society of the Pacific Conference Series, Vol. 493, 19th European Workshop on White Dwarfs, ed. P. Dufour, P. Bergeron & G. Fontaine, 237
Ibata, R. A., McConnachie, A., Cuillandre, J.-C. *et al.* 2017, *ApJ*, 848, 128
Mukadam, A. S., Mullally, F., Nather, R. E. *et al.* 2017, *ApJ*, 607, 982

https://doi.org/10.1017/S1743921320000265 Published online by Cambridge University Press