

White Dwarfs in the *Kepler* Field - What's New?

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Abstract. As white dwarfs cool, they go through instability strips by exhibiting periodic variations about the mean intensity of their light. Asteroseismology can probe the interiors of white dwarfs and provide an insight on their compositions, rotation period, mass, temperature and luminosity, by studying their pulsations. We present our deep optical photometric survey: the *Kepler*-INT Survey. We find 43 new white dwarfs in the *Kepler* field, chosen on the basis of their colours. We also discovered nine new pulsating white dwarfs and present *Kepler* data for four of them. Rotational splitting is detected in all four stars, indicating spin periods of a few days, which confirms that the majority of white dwarfs are slow rotators.

1. Introduction

White dwarfs (WDs) are the end points of more than 95% of stars, including our Sun. As they cool, they all become unstable to global pulsations and evolve through instability strips. Four classes of pulsating WDs are known, each mainly depending on the composition of their envelopes.

Precision asteroseismology of WDs has the potential to probe the masses and compositions of their electron-degenerate cores, as well as of their non-degenerate envelopes (e.g. Winget & Kepler 2008; Fontaine & Brassard 2008), and to determine their internal rotation profiles (Charpinet et al. 2009).

NASA's *Kepler* spacecraft (Borucki et al. 2010) delivers high-quality uninterrupted time-series photometric data, at levels of precision that cannot be achieved from the ground. During the first two years of the *Kepler* mission, only two pulsating WDs were discovered (Østensen et al. 2011; Hermes et al. 2011). It is clear that a full understanding of WD structure and evolution will require a larger sample of targets. With this goal in mind, we began the search for all the WDs, and more specifically the hydrogen-atmosphere ones (ZZ Ceti or DAV stars) in the *Kepler* field by carrying

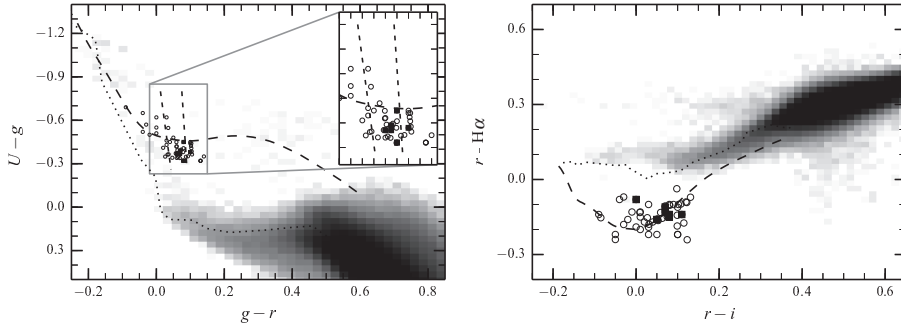


Figure 1. $(U - g, g - r)$ (top) and $(r - H\alpha, r - i)$ (bottom) colour-colour diagrams of stellar sources from the Kepler-INT survey (gray scale), and $\log g = 8$ DA WD cooling tracks (dashed line). The dotted line indicates the Pickles main sequence tracks taken from Groot et al. (2009). Narrowing our colour selection around the first ZZ Ceti in the field identified by Hermes et al. (2011) leaves ≈ 60 WD candidates (open circles). The filled squares correspond to the ZZ Ceti stars we discovered in the Kepler field. The vertical dashed lines mark the empirical $(T_{\text{eff}}, \log g)$ instability strip (Gianninas et al. 2011) projected into $(U - g, g - r)$ space.

out the Kepler-INT Survey (KIS, Greiss et al. 2012a) in order to select WD candidates using colour-colour diagrams.

2. The Kepler-INT Survey

KIS is a deep optical survey of the Kepler field, using four broadband filters, U, g, r, i and one narrowband filter, $H\alpha$, down to $\sim 20^{\text{th}}$ mag in the Vega system. As of December 2012, we have covered 97% of the Kepler field (Greiss et al. 2012b). White dwarfs are bluer than main-sequence stars and most single DA WDs also have strong $H\alpha$ absorption lines, leading to $r - H\alpha < 0$, which makes the KIS filter set ideal for their search (see Figure 1).

In our photometric selection, we recovered KIC 4552982, the first ZZ Ceti star in the Kepler field found by Hermes et al. (2011). We narrowed down our selection to a small region in colour-space centred on KIC 4552982 and to candidates in, or close to the empirical $(T_{\text{eff}}, \log g)$ instability strip (Gianninas et al. 2011) projected into $(U - g, g - r)$ space using the cooling models presented in Tremblay & Bergeron (2009). This left ≈ 60 WD candidates, $\approx 50\%$ of which were ZZ Ceti candidates. Our next step was to confirm their identities via spectroscopy and to search for the variable stars amongst our candidates.

3. Spectroscopy

We were awarded a total of six nights on the William Herschel Telescope (WHT) in 2012 and 2013, where we obtained intermediate resolution spectra of our candidates in order to confirm their identities as WD stars and to measure their atmospheric parameters (T_{eff} and $\log g$). We used the Intermediate dispersion Spectrograph and Imaging

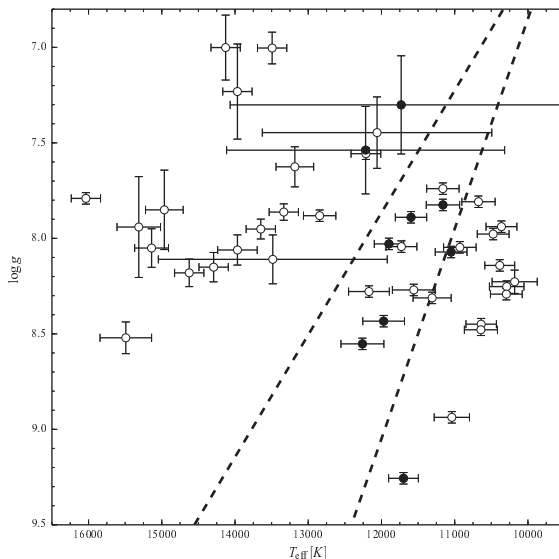


Figure 2. $(T_{\text{eff}}, \log g)$ diagram of all the WDs we observed with ISIS. The filled circles are confirmed pulsators. The black dotted lines correspond to the boundaries of the empirical ZZ Ceti instability strip (Gianninas et al. 2011).

System¹ (ISIS) and observed 43 sources, which were all confirmed to be new DA WDs.

Since we are interested in the ZZ Ceti stars within our DA WD sample, we fitted model atmospheres (Koester 2010) to our spectra in order to obtain their effective temperatures and surface gravities. It is known that ZZ Ceti stars occupy a specific instability strip in $(T_{\text{eff}}, \log g)$ space (Gianninas et al. 2011), making it possible to select ZZ Ceti candidates from our sample of WDs on the basis of those parameters.

In Figure 2, we plot the results from the fits for all our WDs. Out of the 43 new WDs we found in the *Kepler* field. The atmospheric parameters of half of them place them in or very close to the empirical instability strip of ZZ Ceti stars (Gianninas et al. 2011, see Figure 2). The filled circles are confirmed pulsators using ground-based data.

4. Our Pulsating DA WDs

We obtained ground-based optical time-series photometry for nine of our ZZ Ceti candidates, in order to confirm their variable nature. The ground-based observations were obtained from the INT and McDonald Observatory.

Our next step was to obtain *Kepler* time-series photometry of as many DAVs as possible, in order to probe the structure and interior of a wide range of WDs. Asteroseismology has the potential to accurately measure the masses of WDs and to study their degenerate cores, which can never be done via spectroscopy. We obtained DDT *Kepler* observations of four of our ZZ Ceti stars: KIC 11911480, (Greiss et al. 2014),

¹<http://www.ing.iac.es/Astronomy/instruments/isis/>

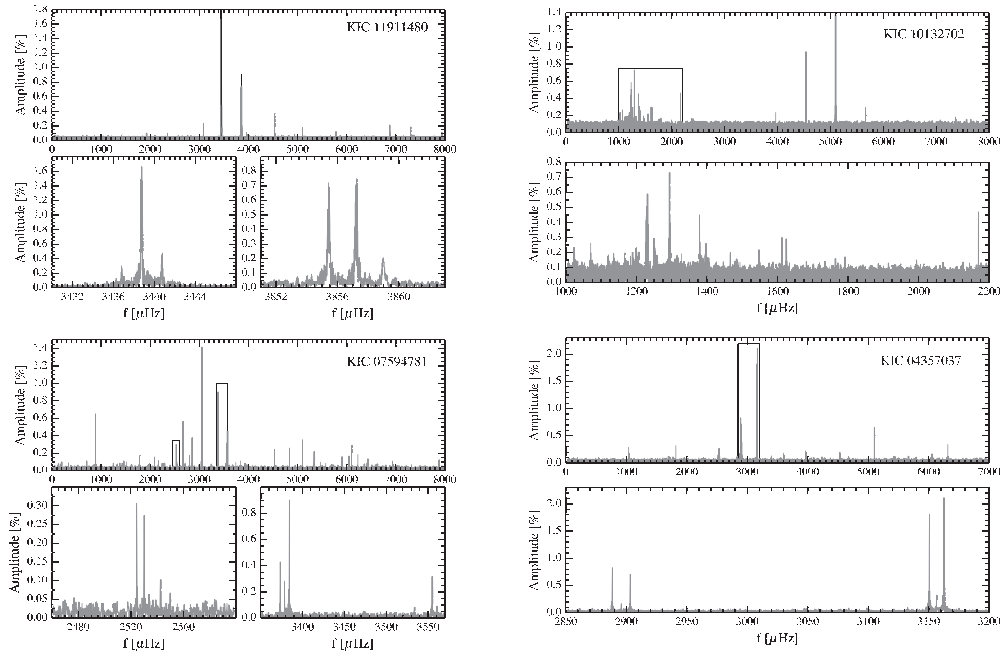


Figure 3. Power spectrum of KIC 11911480. The black boxes define the regions which we zoom into.

KIC 07594781, KIC 04357037 and KIC 10132702 which we present in the following Section.

In Figure 3, we show the power spectra of the four ZZ Ceti stars observed with *Kepler*. We notice splitting of some of the pulsation modes, which is a direct manifestation of the star’s rotation. We estimate their rotation periods by using the frequency spacing between the components and assuming we only see $l = 1$ modes since we mostly only see triplets or doublets. We summarise our findings in Table 1. The periods found are within the expected range for ZZ Ceti stars, which are known to have g -mode pulsations ranging from 100 to 1000 s (Fontaine & Brassard 2008), and match the pulsation periods of other known ZZ Ceti stars (Mukadam et al. 2006).

A detailed asteroseismic study is in preparation in order to identify the correct modes of each ZZ Ceti star and to perform accurate analyses of their interiors.

Table 1. Summary of our results

Source	K_p mag	T_{eff} [K]	$\log g$	Rotation rate [d]	Duration [months]
KIC 11911480	17.6	12 160 (250)	7.94 (0.05)	3.5 ± 0.5	6
KIC 10132702	18.8	11 048 (217)	8.07 (0.08)	3.2 ± 0.5	3
KIC 04357037	18.0	11 898 (200)	8.03 (0.08)	0.9 ± 0.1	1
KIC 07594781	18.2	12 217 (1 700)	7.54 (0.22)	1.1 ± 0.3	1

5. Conclusion

We carried out the *Kepler*-INT Survey to search for WDs, and more particularly pulsating ones, in order to observe them with the *Kepler* spacecraft. We found 43 new DA WDs in the *Kepler* field, all selected on the basis of their colours and confirmed with spectroscopy. Out of these, nine of them show variability from ground-based data.

We obtained Kepler short-cadence observations of four of the DAVs we found before the spacecraft suffered a second reaction wheel failure in 2013 May. All show pulsation periods within the expected range for ZZ Ceti stars and splitting in some of the pulsation modes have enabled us to estimate their rotation periods. We find that they are all slow rotators. We plan to carry on this project with *K2*.

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