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The Search for White Dwarfs in the *Kepler* Field

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Abstract. The *Kepler* mission provides superior time-series photometry, with an enormous impact on all areas of stellar variability. It is therefore a crucial tool for asteroseismology. However, white dwarfs remain an unexploited class of sources within the field. We make use of our deep optical survey of the field, the *Kepler*-INT Survey, to search for white dwarfs on the basis of their colours. In order to exploit *Kepler*'s unprecedented time-series photometry, we search more specifically for pulsating hydrogen-rich (DA) white dwarfs, or ZZ Ceti variables. Asteroseismology has the potential to probe the electron-degenerate cores of those stars, which is impossible via spectroscopy of their atmospheres. We present the discovery of the second, third and fourth ZZ Cetis in the *Kepler* field. Our results corroborate our selection method in the search for white dwarfs and more specifically ZZ Cetis. We expect to find around a *dozen* ZZ Cetis in the *Kepler* field.

1. Introduction

Most stars will end, or have already ended their lives as white dwarfs, and hence studying the galactic population of white dwarfs offers insight into the star formation history of the Galaxy. White dwarfs are very diverse and can be found in single or binary systems, and their study is hence central to a global understanding of stellar evolution. White dwarfs are also the progenitors of type Ia supernovae. However, the biggest challenge with most white dwarfs is that they are small and therefore faint objects. An advantage in searching for white dwarfs is that they have different colours to main-sequence stars and hence stand out in colour-space. Therefore, multi-wavelength surveys are very useful tools in the search for white dwarfs, whether in single or binary systems.

2. The *Kepler*-INT Survey

In a region between the Cygnus and Lyra constellations lies the well-known *Kepler* field. NASA's *Kepler* mission (Borucki, W. J., et al. 2010) was launched in March 2009 with a main goal to find Earth-like planets orbiting Sun-like stars in their habitable zones. The *Kepler* satellite delivers unprecedented time-series photometry, yet due to the limits on the telemetry, only ~ 170,000 stars can be observed at once. Therefore *Kepler* targets must be pre-selected before being observed. *Kepler* data is not only useful for the discovery of exoplanets but it also plays a very important role in asteroseismology (Chaplin, W. J., et al. 2010), stellar activity (Basri, G., et al. 2011), star spot monitoring (Llama, J., et al. 2012), eclipsing and close binary systems (Prša, A., et al. 2011; Coughlin, J. L., et al. 2011; Bloemen, S., et al. 2011), gyrochronology (Meibom, S., et al. 2011) and accreting white dwarfs (Fontaine, G., et al. 2011; Still, M., et al. 2010; Wood, M. A., et al. 2011).

The main catalogue used up to pre-select *Kepler* targets was the *Kepler* Input Catalog (KIC, Brown, T. M., et al. 2011). However, this catalogue is only reliable down to 16^{th} mag, i.e. the *Kepler* field lacked deep optical photometry. The rather shallow limiting magnitudes of KIC prevented the selection of white dwarfs and many other interesting and faint objects in the field. Therefore, a European collaboration has carried out the first deep optical survey of the field: the *Kepler*-INT Survey (KIS, Greiss, S., et al. 2012). This survey covers the entire 116 deg^2 *Kepler* field in four broadband filters, $Ugri$, and one narrowband filter, Hα. Using this range of filters it is easy to select white dwarfs on the basis of their colours since they have bluer colours than main-sequence stars and most single white dwarfs also have Hα absorption. The observations are carried out using the Wide Field Camera on the 2.5m Isaac Newton Telescope (INT) on the island of La Palma in Spain. The observing strategy and data processing recipe are identical to those used by the European Galactic Plane Surveys consortium (IPHAS, Drew, J. E., et al. 2005, UVEX, Groot, P. J., et al. 2009, VPHAS+, Drew et al. in prep). Many interesting and exotic objects can be found in the galactic plane, yet due to the high extinction towards that region, many astronomers have been reluctant to explore it. IPHAS and UVEX data have been used to develop selection methods to detect different objects such as Hα emitters (Witham, A. R., et al. 2006), cataclysmic variables (Witham, A. R., et al. 2007), planetary nebulae (Viironen, K., et al. 2009) and UV-Excess sources (Verbeek, K., et al. 2012). In Fig. 1, we show the coverage of the galactic plane surveys (IPHAS, UVEX, VPHAS+), of the *Kepler*-INT Survey, and, for comparison, the photometric footprint of SDSS, which indicates that the galactic plane and *Kepler* field are unexploited regions.

KIS's initial data release, covering ~ 50% of the field, was released in the beginning of 2012 and contains ~ 6 million objects. The survey depth is ~ 20^{th} mag. in the Vega system. A second and final data release is planned for late 2012. In Fig 2, we show a colour-colour diagram of all stellar objects in the initial data release of KIS, and indicate the location of the known cataclysmic variables, white dwarfs, subdwarfs and active galactic nuclei in the field. As can be seen, the different types of objects fall within their expected locations in colour-space. More specifically, we notice that single hydrogen-rich (DA) white dwarfs stand out as blue objects in the top panel of the figure

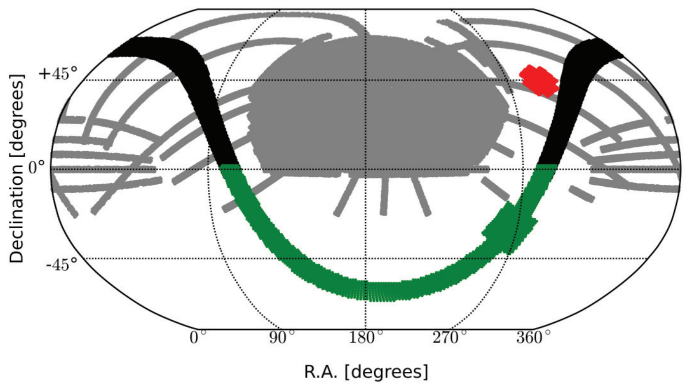

Figure 1. Sky coverage of several recent large area surveys. The grey region represents the photometric footprint of SDSS, the black area is the northern galactic plane (IPHAS, UVEX), the green area is the southern plane and bulge (VPHAS+) and the red region corresponds to the *Kepler* field (KIS). As can be seen, the galactic place strip and *Kepler* field are distinct regions and only overlap in the small areas with SDSS.

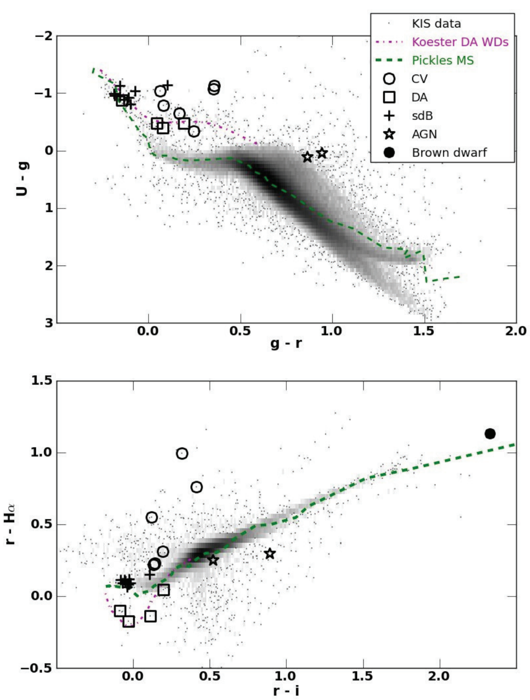

Figure 2. KIS colour-colour diagrams of all stellar objects in the initial data release catalogue.

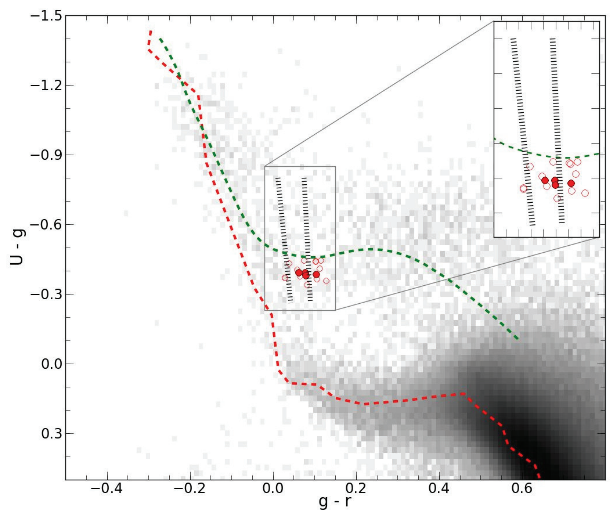

Figure 3. KIS colour-colour diagram showing the ZZ Ceti candidates from KIS. The red filled circles correspond to confirmed ZZ Cetis and the open circles are candidates. The black dashed lines are the instability strip boundaries in colour-space.

and as Hα deficit objects (due to their broad Hα absorption line) in the bottom panel of Fig 2.

3. The search for ZZ Cetis in the *Kepler* field

There are four known classes of pulsating white dwarfs: the hot pre-white dwarfs (PG 1159 or DOV stars), warm helium-atmosphere white dwarfs (V777 Her or DBV stars, $T_{\rm eff} \simeq 22\,000 - 29\,000$ K), cool hydrogen-atmosphere white dwarfs (ZZ Ceti or DAV stars, $T_{\rm eff} \simeq 10\,900 - 12\,300$ K), and the recently discovered carbon-atmosphere white dwarfs (DQV, $T_{\rm eff} \simeq 20000$ K, Dufour, P., et al. 2008). The most common type of pulsating white dwarf found is the ZZ Ceti class. In the case of white dwarfs, asteroseismology is very useful in order to probe the interior of the star, more precisely the mass and composition of their electron-degenerate cores, as well as their envelopes (Winget & Kepler 2008; Fontaine & Brassard 2008), to measure weak magnetic fields (Winget, D. E., et al. 1991), to constrain nuclear reaction rates (Metcalfe, T. S., et al. 2002) and to detect the presence of planetary companions via pulse timing variations (Mullally, F., et al. 2008).

In order to add to the only known ZZ Ceti in the *Kepler* field of view (Hermes, J. J., et al. 2011), we search for them in the *Kepler* field to be able to make use of the quality of the uninterrupted data delivered by the *Kepler* satellite. We use KIS photometry to select ZZ Ceti candidates on the basis of their colours (see Fig. 3), by selecting sources near the first ZZ Ceti found in the field by (Hermes, J. J., et al. 2011). Next we follow-up the candidates using ground-based time-series photometry and spectroscopy in order to check if they are variable sources and to confirm their identities. Obtaining good signal-to-noise spectra of our targets is essential to measure accurate temperatures and surface gravities, in order to determine whether they fall within the instability strip of ZZ Cetis (see Fig. 4). Using this selection method, we found the second, third and fourth ZZ Cetis in the *Kepler* field.

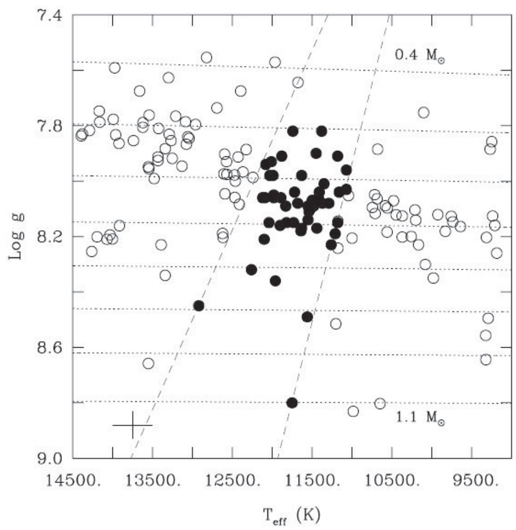

Figure 4. Instability strip of ZZ Cetis in effective temperature-log g space taken from Van Grootel, V., et al. 2012. Similar studies have been carried out by Gianninas, A., et al. 2007; Fontaine & Brassard 2008; Castanheira, B. G., et al. 2010.

3.1. The second ZZ Ceti in the *Kepler* field: KIC 11911480

The second ZZ Ceti was confirmed through the Rapid Temporal Survey (RaTS) of the *Kepler* field (Brooks et al. in prep), which obtains time-series photometry using the INT. We also obtained *Kepler* short cadence observations of this object during quarter 12 (Gänsicke et al. in prep). Finally, we obtained a spectrum of the source using ISIS on the WHT. The best-fit atmospheric parameters are $T_{\rm eff}$ = 11 972 ± 63 K and log g = 8.16 ± 0.03. The KIS g-band magnitude of this ZZ Ceti is 18.094 ± 0.015.

3.2. The third ZZ Ceti in the *Kepler* field: KIC 10132702

The third ZZ Ceti was confirmed through time-series photometry obtained at the McDonald Observatory in Texas. WHT ISIS spectra were also obtained and the effective temperature and surface gravity were determined to be $T_{\rm eff}$ = 11 699 ± 14 K and log g = 8.26 ± 0.03 (see Fig. 5. Once again, these values fall in the instability strip of ZZ Cetis. The KIS g-band magnitude of this source is 19.085 ± 0.026, making it even fainter than the second pulsating ZZ Ceti discovered. We have been approved for short cadence *Kepler* time for quarter 15 and are awaiting the observations to begin.

3.3. The fourth ZZ Ceti in the *Kepler* field: KIS J1923+3929

The fourth ZZ Ceti was also confirmed through the same run at the McDonald Observatory in Texas. This object has a KIS g-band magnitude of 19.434 ± 0.013 and is

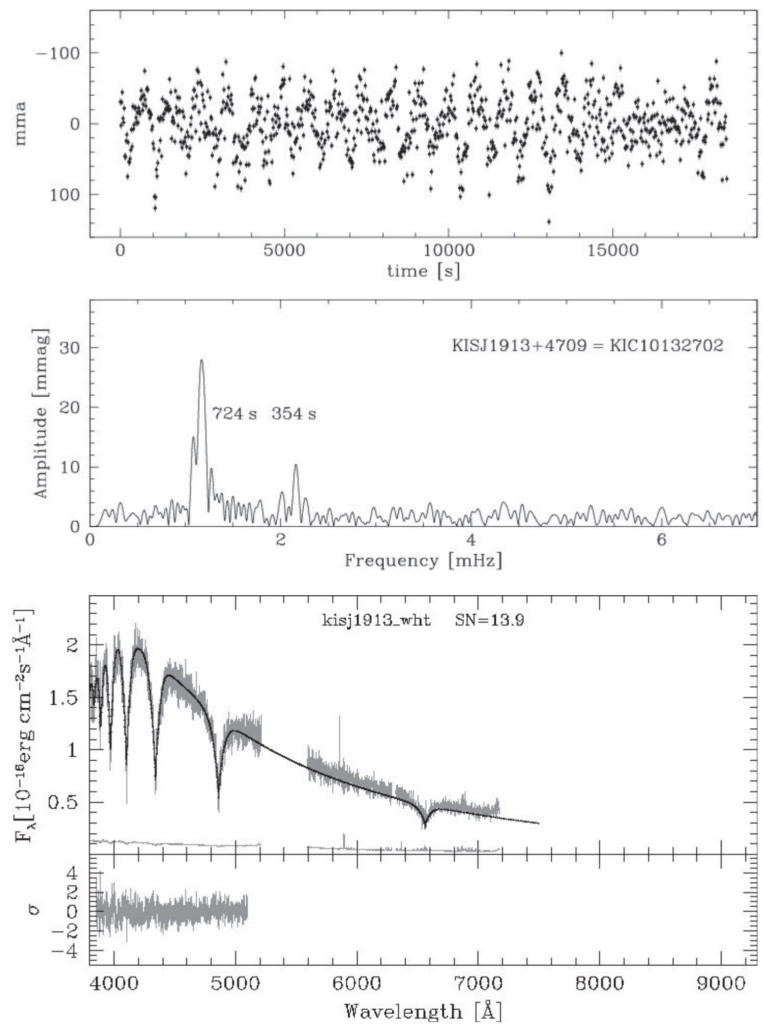

Figure 5. McDonald Observatory light-curve of KIC 10132702 (top), power spectrum (middle) and fit to WHT ISIS spectrum (bottom) of KIC 10132702.

fainter than the previous candidates found. Unfortunately, it falls between the gaps of the CCDs on the *Kepler* satellite and will therefore never be observed by *Kepler*. It was also too faint to observe during our WHT run due to weather conditions.

4. Conclusions

Multi-wavelength surveys such as IPHAS, UVEX and KIS have proven to be a very useful tool in the search for many types of objects, including white dwarfs. We carried out the first deep optical survey of the *Kepler* field, the *Kepler*-INT Survey (Greiss, S., et al. 2012), using a bluer than *g* filter as well as a narrowband Hα filter. Our goal is to identify as many white dwarfs, more specifically pulsating white dwarfs, as possible in the *Kepler* field. We have discovered the second, third and fourth ZZ Cetis in the *Kepler* field, but only two of them are being followed-up by *Kepler* (the fourth one always falls in between the gaps of the CCDs onboard the satellite). The KIS survey now fully covered the entire *Kepler* field and we will soon release the final KIS catalogue. We expect to find *a dozen* pulsating white dwarfs in the field.

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