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/S174392132000023X

Searching for low-mass companions around white dwarfs and subdwarfs from Kepler field

Jurek Krzesinski[1] **and Adam Blokesz**[2]

[1]Astronomical Observatory of the Jagiellonian University, ul. Orla 171, 30-244 Krakow, Poland
email: jk@oa.uj.edu.pl

[2]Pedagogical University of Cracow, ul. Podchorazych 2, 30-084 Cracow, Poland
email: abl@astro.as.up.krakow.pl

Abstract. Knowing the late stages of the stellar evolution is crucial for understanding the fate of planets around subdwarfs and white dwarfs. Simulations by Staff *et al.* (2016) show that exoplanets engulfed in the extending stellar envelope will quickly spiral down onto the parent star. Therefore, we do not expect to find planets on close by orbits to the subdwarfs (Blokesz *et al.* 2019) or white dwarfs. However, the recent observation of planetary debris around WD 1145+017 white dwarf suggests, there might exists planets farther away from these stars. Using binarograms, O-C diagrams and Fourier transform for the Kepler space telescope data, we investigate a problem of missing planets around white dwarfs in binary systems, single white dwarfs and subdwarfs type B. The last ones, being the only stars which (due to the lack of hydrogen) go directly to the white dwarf cooling track after their red giant phase.

Keywords. (stars:) planetary systems, (stars:) subdwarfs, (stars:) white dwarfs, (stars:) binaries: general

1. Introduction

Most of the stars have their exoplanetary systems around them. During the evolution, the host stars go through the red giant (RG), horizontal branch and asymptotic giant (AGB) phases on the HR diagram before they become white dwarfs. However, even though white dwarfs (WD) and subdwarfs are considered to be the best objects for exoplanet searches, no exoplanets have been found around any of them. There were reports on a discovery of exoplanets around the horizontal and extreme horizontal branch stars in the past ten years, but all of them awaited the counterpart papers denying the existence of exoplanets.

The lack of exoplanets around WDs suggests that planets are lost after their hosts stars leave the main sequence. The hydrodynamic simulations by Staff *et al.* (2016) show, that for 10 M_J planet it takes less than 3 years to spiral down onto 3.5 $M_\odot$ host star, if the planet gets engulfed by the stellar envelope during the RG, and less than 100 years during the AGB phases. Therefore we can expect, there are no nearby survivors to the host stars. Any planet which had survived the RG/AGB phase, should be further away than the RG/AGB radius of the host star.

Recent observation of the disintegrating planetary debris around the WD 1145+017 (Vanderburg & Rappaport 2018) could be the indirect indication for the planetary presence around white dwarfs. If present, the exoplanets further away from a white dwarf could perturb asteroid orbits, so the rocky material falls onto the WD.

Table 1. The list of analyzed objects

KIC ID#	Type	Mass in $M_\odot$	ref.	remarks
KIC 8626021	DBV	0.55	1	single
KIC 9472174	sdBV+dM	$0.48 + 0.12$	2	eclipsing binary, $P_{orb} = 0.12576528$ d
KIC 7975824	sdB+WD	$0.47 + 0.59$	3	eclipsing binary, $P_{orb} = 0.40375026$ d

Notes: [1](Giammichele *et al.* 2018), [2](Zola & Baran 2013), [3](Bloemen *et al.* 2011)

2. Search and analysis techniques

To find out how far away from the WD (or subdwarf) the exoplanets might have survived, we began our search for planets around extreme horizontal branch stars, WDs, as well as binary stars (the common envelope phase would also affect the exoplanetary systems evolution). One of the most important stars for our investigations are B-type subdwarfs (sdB). These stars lost most of the hydrogen from their envelope before the helium flash, therefore after the RG phase they will go directly to the WD cooling track omitting the entire AGB phase. As such, sdBs allow to track the fate of the exoplanetary systems (if present) right after the host star RG phase.

Our analysis techniques were based on the O-C diagrams for eclipcing binary systems, Fourier Transform (FT) of the light curves and binarograms. The "binarogram" term was introduced by Ballona (2014). In short, this method is designed to detect the time-delay effect in the most efficient way using pulsation frequencies as a clock. The method was successfully tested on delta Scuti stars (about ∼1.5 as massive as the Sun). The lowest mass limit of an object, which could be detected with this method, was estimated to be $\sim 2\ M_J$. Because sdB and WD masses are smaller than the delta Scuti stars, we might be able to detect lower-mass objects.

For our analysis we used Kepler space telescope data (the primary mission) of several sdBs, WDs and eclipsing binaries. This report outlines the results obtained for three objects listed in Table 1.

3. Light curves analysis

KIC 8626021: a pulsating helium atmosphere WD (DBV) showing a rich pulsating frequency spectrum in its light curve FT. The short cadence (SC) Kepler date was analyzed using the binarogram method. Due to the variability in the pulsation mode amplitudes and frequencies of the star, the resulting binarograms were contaminated by a number of artifact orbital frequencies. Therefore to rule out the artifacts, binarograms were calculated for different sets of frequencies (taken from Giammichele *et al.* 2018) as well as two halfs of the data. The real orbital signal should be independent on the data and frequency sets used for calculations and it should have the same frequency and amplitude with the accuracy corresponding to the binarogram noise. The noise and the $4\,\sigma$ detection thresholds in binarograms were calculated similar way as the noise in FT.

As a result, all signals visible within 0.001–3.0 c/d orbital frequency range of the KIC 8626021 binarogram were ruled out and classified as artifacts.

KIC 9472174: since the star is an eclipsing binary (composed of the red dwarf and sdBV stars, see Table 1), we used the eclipses to calculate times of minima and the O-C diagram. The star was analyzed this way before by Baran *et al.* (2015), where mid-eclipse times were calculated using Kwee-van Woerden method (KW) (Kwee & van Woerden 1956), after prewhitening pulsation modes of the sdBV from the SC Kepler data. From their O-C diagram shape (Fig. 1), authors inferred the presence of the $\sim 2\ M_J$ mass object on the 0.9 AU orbit around the system. The orbital period of the putative exoplanet was estimated to be around 412 days (0.0024 c/d).

https://doi.org/10.1017/S174392132000023X Published online by Cambridge University Press

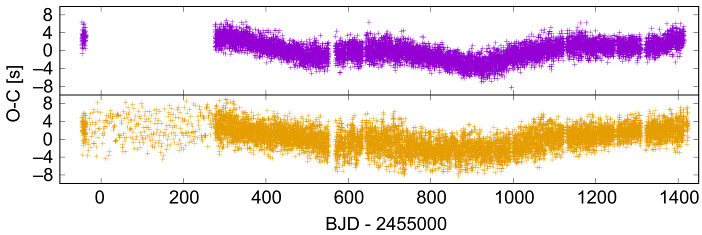

Figure 1. KIC 9472174 O-C diagrams: Baran *et al.* (2015) (top) and our (bottom). Sparse points (near 0–200 BJD) in the figure correspond to the LC data.

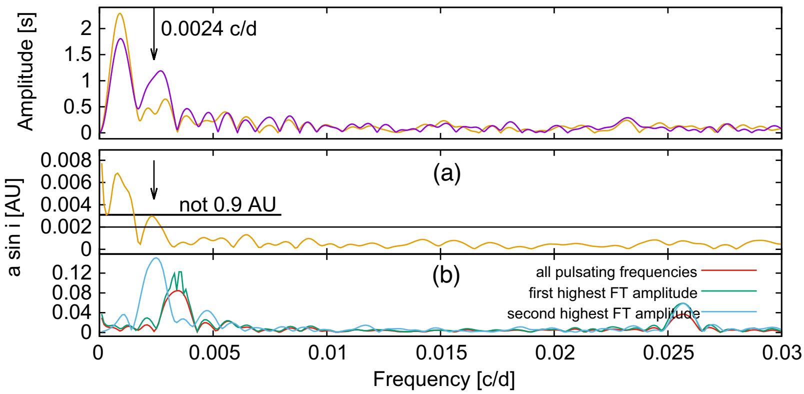

Figure 2. KIC 9472174. Top - FT of the O-C diagram shown in Fig. 1 (violet - Baran *et al.* 2015; yellow - our O-C diagram). Bottom - binarograms calculated using a) - the orbital frequency of the KIC 9472174 binary and b) - pulsation frequencies of the sdBV component. The vertical arrows show the orbital frequency of the putative exoplanet.

Since the SC data cover the light curve minima with 11-13 points only, we decided to use a light curve template and the least square method, to fit this template to the KIC 9472174 data and calculate minima times this way. The template of the binary light curve was prepared by phasing and averaging the whole light curve. In addition to SC data, we also used the long cadence (LC) light curve of the binary to calculate mid-eclipse times. In this case however, the template was composed of the multiple of 10 phased and averaged LC data (to compensate for the poor data point coverage of the light curve). The resulting O-C diagram is presented at the bottom of Fig. 1, where the sparse pints in the figure correspond to the LC data. We did not prewhitened pulsation frequencies from the data, therefore we think, we observe larger scatter in our O-C diagram (comparing to the O-C scatter in the upper panel of Fig. 1).

Thanks to the length of the Kepler data, the number of minima points in the O-C diagram is large enough to calculate the Fourier transform (FT) out of the O-C curve. This allows to determine the amplitude and frequency of the O-C variations from the FT amplitude spectra, instead of guessing the best model which would fit these variations. A top panel of Fig. 2 shows the FT of both Baran *et al.* (2015) (violet) and our (yellow) O-C diagrams. It appears, the signal amplitude near the orbital frequency of the putative exoplanet (marked with the vertical arrows) is ∼twice lower in the FT of our O-C than Baran *et al.* (2015) one.

The bottom panels of Fig. 2 present binarograms calculated using a) - the orbital frequency of the KIC 9472174 binary, b) - frequencies of the pulsating modes of the sdBV component. Neither of the two binarograms show signals near the orbital frequency (nor

https://doi.org/10.1017/S174392132000023X Published online by Cambridge University Press

the amplitude) of the putative exoplanet (the vertical arrow). The signal visible in the panel a) (below the arrow) has a very low amplitude (a$\times$sin(i) $\sim$0.003 AU), meaning - the planet would have to be very close to the binary (while Baran *et al.* 2015 gives the $\sim$0.9 AU distance). The binarograms calculated using pulsation frequencies in the panel b) show several signals, but all of them were ruled out as artifacts. In the result we neither found any planet nor confirm the existence of a Jupiter-mass exoplanet around this binary system (within 0.001–0.03 c/d orbital frequency range). The observed variations in the O-C diagram, needs further investigations but they are not due to the exoplanetary presence. At the time of writing, we can only speculate, the variations might be due to spots on the dM component or amplitude modulations of the pulsation modes of the sdBV star.

KIC 7975824: another eclipsing binary composed of sdB and WD stars. Using the template method fitting (as described above), we determined the mid-time of eclipses. In the O-C diagram and in its FT, we do not see any variations. The binarograms calculated using the orbital frequency of the system are noisy. Based on them and on the O-C diagram, we can rule out the existence of any Jupiter-mass exoplanet within the 0.001–0.03 c/d orbital frequency range. After subtraction of the template light curve from the binary system LC and SC light curves, we confirmed that neither of the binary component is a variable (Bloemen *et al.* 2011).

Summary Using the binarogram, FT and O-C methods we analyzed the light curve of two binaries and one pulsating WD. We ruled out the existence of any Jupiter-mass planet within the 0.001–0.03 c/d orbital frequencies around these objects.

Acknowledgements

This work was supported by the National Science Centre, Poland. The project registration number is 2017/25/B/ST9/00879.

References

Baran, A.-S., Zola, S., Blokesz, A., Ostensen, R.-H., & Silvotti, R. 2015, *A&A*, 577, A146
Ballona, L. 2014, *MNRAS*, 443, 1946
Blokesz, A., Krzesinski, J., & Kedziora-Chudczer L. 2019, *A&A*, 627, A86
Bloemen, S., Marsh, T.-R, Ostensen, R.-H., *et al.* 2011, *MNRAS*, 410, 1787
Giammichele, N., Charpinet, S., Fontaine, G., *et al.* 2018, *Nature*, 554, 73
Kwee, K. K. & van Woerden, H. 1956, *Bull. Astron. Inst. Neth.*, 9, 252
Staff, J., De Marco, O., Wood, P., Galaviz, P., & Passy, J.-C. 2016, *MNRAS*, 458,832
Zola, S. & Baran, A. 2013, *Central Eur. Astrophys. Bull.*, 37, 227
Vanderburg, A. & Rappaport, S.-A. 2018, *Handbook of Exoplanets (New York: Springer International Publishing AG)*

https://doi.org/10.1017/S174392132000023X Published online by Cambridge University Press