ORBITAL PERIODS AND FLARE RATES OF WHITE DWARF - MAIN SEQUENCE STAR BINARIES WITH TESS

1 Introduction

A large fraction of stars undergo evolution through a common envelope into a close white dwarf - main sequence binary. Thousands of such systems have been identified spectroscopically via large surveys such as SDSS, but in most cases the orbital period is unknown. Here we propose to obtain *TESS* photometery to search for orbital periods and stellar activity at hundreds of binary systems.

2 Scientific Justification

The majority of stars in the sky a.) are found in binary systems and b.) will end their stellar evolutionary pathways as white dwarfs. **Binary systems containing at least one white dwarf are therefore a common product of the galaxy,** and thousands of such systems have been identified over the past decades [18]. Of particular interest are the ∼25 percent of binaries that are close enough that the more massive star will engulf its companion when it reaches the giant stages [20], forming a common envelope. The companion then spirals in, ejecting the giant envelope as it does so, leaving a binary system with an orbital period of just hours to a few days. Such Post-Common Envelope Binaries (PCEBs) are the progenitors for some of the most astrophysically interesting objects, such as cataclysmic variables, novae, Type-1a supernovae and double white dwarf binaries that will be the dominant source of

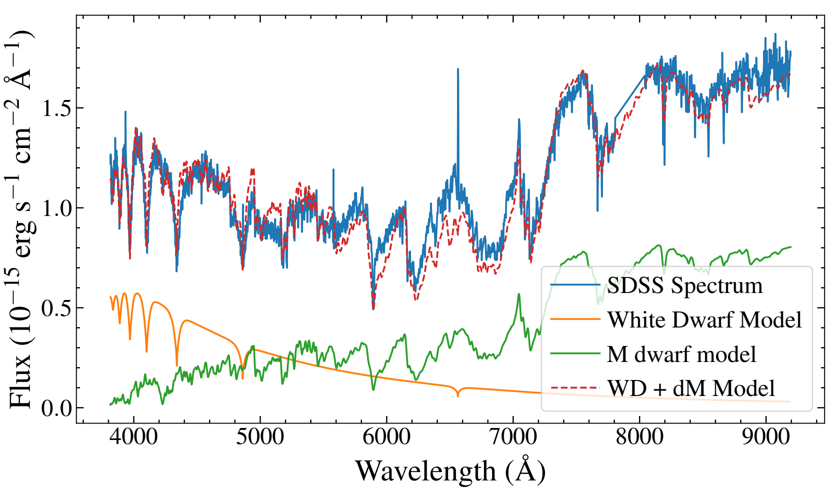

Figure 1: SDSS spectrum of a white dwarf - M dwarf binary (blue) [18]. The models of a white dwarf (orange) and M dwarf (green) fit the unusual spectrum when combined (red), with the exception of strong emission features resulting from the M dwarf's short rotation period. Such systems are easily identifiable spectroscopically, but measuring their orbital periods requires dedicated follow-up or the high-cadence phototmetry provided by TESS.

gravitational waves detected by LISA [8]. They are also remarkable in their own right. PCEBs can be used to, for example, constrain the mass-radius relations of the component stars [15], measure stellar winds [6], search for the elusive origins of magnetic white dwarfs [13, 21], and disentangle the age-rotation-activity relation of M dwarfs [19]. **Each of these areas of investigation requires detailed knowledge of the stellar parameters of the system components as well as, crucially, the binary orbital period.**

As M dwarfs make up the majority of main-sequence stars, it naturally follows that the majority of main sequence stars in PCEBs are M dwarfs. Such systems are easy to identify with ground-based survey spectroscopy, as the white dwarf and M dwarf contribute roughly equal flux, but in different wavebands. Figure 1 shows an SDSS optical spectrum of a PCEB identified by [18], as well as the model spectra used to explain the unusual combination of spectral features. By examining all candidate spectra up to SDSS DR12, [17, 19, 18] identified over 3200 white dwarf-main sequence binaries, by far the largest homogeneously-selected sample to date. However, SDSS provides only limited time-series observations, so **the binary periods for the majority of the sample are unknown.**

Whilst ground-based surveys such as ZTF can efficiently identify the small fraction of the sample that eclipses [4], the non-eclipsing systems produce lower amplitude (a few percent), orbit-long signals (Figures 2 and 3). Three photometric signals are dominant: Reflection, where the flux from the white dwarf heats the day side of the companion, producing a sinusoidal light curve on the orbital period; ellipsoidal modulation where the tidal stretching of the companion produces a modified sinusoid on twice the orbital period; and starspot modulation on the main sequence star, which is tidally locked to the orbital period in most systems [12]. These effects are often combined, and modelling of the light curve can be used to distinguish between them (e.g. [5]). Critically, all of these effects are modulations of the flux of the *main-sequence star*: The low flux of the white dwarf in the *TESS* bandpass does not affect their detectability. Both theory and observations predict that the orbital periods fall in the range of a few hours to a few days[12, 1] — exactly the range that *TESS* is best-suited to explore. **In summary, *TESS* is the ideal instrument with which to search for the orbital periods of the non-eclipsing PCEBs.**

Here, we will survey all of the SDSS PCEBs bright enough for their periods to be detected in *TESS*. Based on the sucess rate of previous photomoetric surveys (e.g. [14, 12]), we expect to identify ≈ 100 new binary periods, greatly improving the statisitcs of the observed period distributions. These relatively bright PCEBs also represent the preferred targets for follow-up observations for the many science cases described above. Cycle 6 is the ideal time to undertake this survey as it focuses on the Northern hemisphere, providing good overlap with the SDSS sample.

Furthermore, *TESS* allows the detection of stellar flares on the PCEB main sequence stars. These stars are tidally locked, so the age-rotation relationship of single stars is removed. [19] measured the activity level of 191 PCEBs using H α, finding them to be on average more active than both wide binaries and single stars. Stellar activity science has considerably advanced since that work, and we can use *TESS* to measure the Flare Frequency Distribution (FFD) for each of our targets [10] and compare them as function of rotation period with wide binaries and single stars.

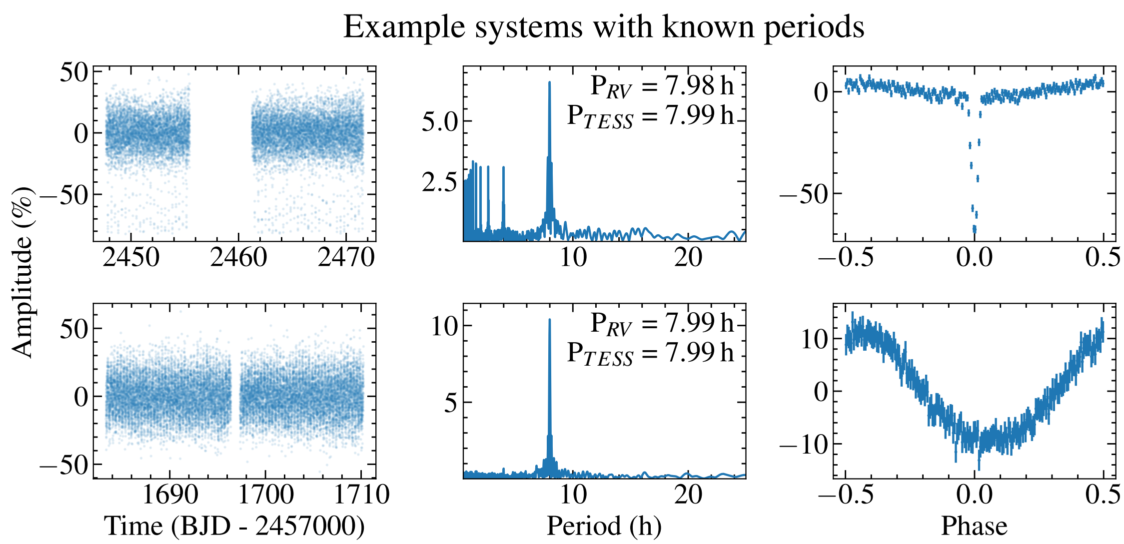

Figure 2: Binaries with known periods from the [18]. From left to right: Normalised 2-minute cadence *TESS* light curve; Lomb-Scargle periodogram of the light curve; and the light curve folded onto the strongest period from the periodogram. The periods identified in the *TESS* data agree with those measured from SDSS radial velocity measurements to within less than a percent.

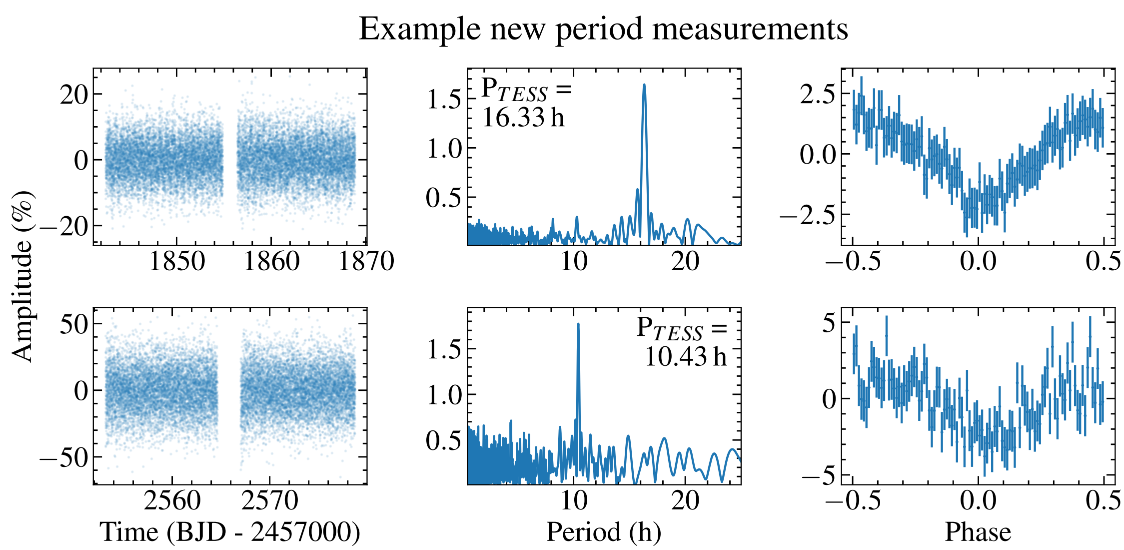

Figure 3: As Figure 2, but for binaries without period measurements chosen at random from our sample. In both cases periodic modulation is clearly detected in the TESS light curve.

3 Analysis Plan

We request 2-m cadence data to make use of the pipeline-processed light curves, ensuring a uniform and easily reproducible dataset. For each target, we will use the LightKurve package [9] to remove long-term trends, normalise the light curves and produce periodograms, as well as combine data from multiple sectors if appropriate. To identify significant periods we will use a false alarm probability assessment [3] as well as visual inspection of the light curves. We will measure precise periods and ephemerides via sinusoidal fits to the light curves with astropy [2]. Stars where a single period cannot be identified (e.g. if we cannot distinguish between ellipsoidal variation and reflection) will be flagged. We will use stella [7] to identify flares in the light curves, fitting them and measuring fluxes with the flare model from [11] to construct a FFD for each star.

4 Target Selection and Technical Feasibility

The targets were selected from the list of white dwarf-main sequence binaries from [18] complied at https://sdss-wdms.org/. We used the *TESS* S/N calculator and searches of *TESS* light curves from a random sample to establish a magnitude cut of $i_{mag} < 18$. We find 544 targets observable in *TESS* Cycle 6, providing by far the largest homogeneous sample of white dwarf-main sequence binaries light curves to date. We do not cut the catalog's wide binary candidates, as we can still search for the rotation periods of their main-sequence stars via spot modulation.

Around 50 of the targets in the sample have known periods based on radial velocity data. We did not exclude these targets, as they can be used as a confidence check to ensure that the periods found in *TESS* match those from RV. Figure 2 shows *TESS* light curves from two targets selected at random with known periods. We find the periods found from just a single *TESS* sector match those measured from RV to well within a percent. The light curves also contain information not revealed by RV measurements, for example the system in the top panel is a (known [16]) eclipsing binary.

To demonstrate that *TESS* can identify new periods, we selected several systems with existing 2-m *TESS* data at random and searched their light curves for periodicity. Figure 3 shows two examples of PCEBs with periodic flux modulations identified with *TESS*.

We did not exclude targets with existing two minute data, as combining light curves from multiple sectors will improve the S/N and therefore the precision of our period fits and ephermeris measurements, as well as provide a longer baseline for flare detection.

5 Expected Impact

This program will be the largest homogeneous search for non-eclipsing PCEB periods to date. We will survey over 500 stars, providing a catalog of ≈ 100 periods and sub-percent limits on optical variation at the remaining stars. The sample will massively improve the statistics of the observed period distribution of PCEBs and provide periods for the bright PCEBs most amiable to further study. Additionally, we will provide FFDs as a function of orbital/rotation period for our sample, testing the spin-activity relationship in comparison to that found at single stars.

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