Discovery of a Detached, Eclipsing 40 Minute Period Double White Dwarf Binary and a Friend: Implications for He+CO White Dwarf Mergers*

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Abstract

We report the discovery of two detached double white dwarf (WD) binaries, SDSS J082239.546+304857.19 and SDSS J104336.275+055149.90, with orbital periods of 40 and 46 minutes, respectively. The 40 minute system is eclipsing; it is composed of a 0.30 \( M_\odot \) and a 0.52 \( M_\odot \) WD. The 46 minute system is a likely LISA verification binary. The short 20 \( \pm \) 2 Myr and \( \sim 34 \) Myr gravitational-wave merger times of the two binaries imply that many more such systems have formed and merged over the age of the Milky Way. We update the estimated Milky Way He+CO WD binary merger rate and affirm our previously published result: He+CO WD binaries merge at a rate at least 40 times greater than the formation rate of stable mass-transfer AM CVn binaries, and so the majority must have unstable mass-transfer. The implication is that spin–orbit coupling in He+CO WD mergers is weak, or perhaps nova-like outbursts drive He+CO WDs into merger, as proposed by Shen.

Key words: binaries: close – Galaxy: stellar content – white dwarfs

Supporting material: data behind figures

1. Introduction

There are about 100 double-degenerate white dwarf (WD) binaries known with orbital periods less than about 1 day (e.g., Saffer et al. 1988; Braggaglia et al. 1990; Marsh et al. 1995; Moran et al. 1997; Maxted et al. 2000; Morales-Rueda et al. 2005; Nelemans et al. 2005; Vennes et al. 2011; Brown et al. 2016a; Breidt et al. 2017; Kilic et al. 2017; Rebassa-Mansergas et al. 2017). Short-period WD binaries with periods less than 1 hr have gravitational-wave merger times less than about 100 Myr, and thus are interesting gravitational-wave sources at mHz frequencies (Nelemans 2009; Marsh 2011; Nissake et al. 2012). The 765 s orbital period binary J0651 (Brown et al. 2011), for example, should be detected by the proposed LISA gravitational-wave detector shortly after it is turned on (Korol et al. 2017). Short-period WD binaries are also interesting because they must either evolve into stable AM CVn systems, explode as supernovae, or merge into single massive WDs, R CrB stars, and related objects (e.g., Webbink 1984; Iben 1990). None of these transformations have been observed directly, but we can compare WD merger rates with different rates to constrain their outcome.

Here, we report the discovery of two detached, double WD binaries, SDSS J082239.546+304857.19 and SDSS J104336.275+055149.90, with orbital periods of 40 and 46 minutes, respectively. We will henceforth refer to these objects as J0822 and J1043. J0822 and J1043 are the fifth- and sixth-shortest-period WD binaries discovered by our Extremely Low Mass (ELM) Survey, a targeted spectroscopic survey for extremely low mass \( \approx 0.2 \) \( M_\odot \) He-core WDs (Brown et al. 2016a and references therein). Thus, we refer to degenerate \( \approx 0.2 \) \( M_\odot \) objects as ELM WDs. Practically all ELM WDs are observed in compact binaries, with typical \( M_2 = 0.76 \pm 0.25 \) \( M_\odot \) WD companions and median \( P = 5.5 \) hr periods (Brown et al. 2016a). J0822 and J1043 bring our ELM Survey sample to 82 binaries, more than half of which have merger times less than a Hubble time.

Eclipses provide accurate constraints on the physical parameters of binaries. J0822 is the seventh eclipsing double WD binary known after NLTT 11748 (Steinfadt et al. 2010), CSS 41177 (Drake et al. 2010; Parsons et al. 2011), GALEX J11717 (Vennes et al. 2011), SDSS J0651 (Brown et al. 2011), SDSS J0751 (Kilic et al. 2014b), and SDSS J1152 (Hallakoun et al. 2016). J0822 has a total mass of 0.82 \( M_\odot \) and a mass ratio of about 1:2, and will merge in 20 Myr.

The existence of double WD binaries with \( \sim 10 \) Myr merger times implies that many more such systems have formed and evolved over the age of the Milky Way. Conversely, longer-period systems remain binaries for the age of the Milky Way and must accumulate in observed samples. An obvious question is what merging ELM WD binaries like J0822 and J1043 become.

Previously, we used the magnitude-limited ELM Survey to estimate the local space density of ELM WD binaries and then to calculate their merger rate by (1) inverting the distribution of merger times and (2) by forward-modeling different trial distributions to match the observations. The major source of uncertainty comes from the small number statistics of rapidly merging binaries. The gravitational-wave merger timescale depends most strongly on orbital period (Kraft et al. 1962), so the shortest-period binaries dominate the merger rate estimate. Given that J0822 and J1043 increase the sample of ELM WD binaries by 40%, we revisit the merger rate estimate in light of the new discoveries.

We begin by presenting our spectroscopic and photometric observations of J0822 and J1043. We fit stellar atmosphere models to the spectra, orbital parameters to the radial velocities, and light curve parameters to the photometry. The Galactic kinematics of the binaries suggest that J0822 is a halo object,
while J1043 is a thin disk object. We discuss the mass and mass ratio of J0822 in the context of other eclipsing double WD binaries, and we close with an update on the merger rate of He +CO WD binaries in the Milky Way.

2. Data

2.1. Target Selection

The ELM Survey is a spectroscopic survey of low-mass WD candidates selected on the basis of broadband color (Brown et al. 2012). We have also targeted some objects on the basis of stellar atmosphere fits to pre-existing Sloan Digital Sky Survey (SDSS) spectra (Kilic et al. 2010, 2011a, 2014a). J0822 is an example of an object identified from its SDSS spectrum. In 2016 February, we obtained a pair of spectra to validate its nature and test for radial velocity variability. We followed up J0822 with time-series spectroscopy in 2016 October and 2017 March to determine its orbit.

We targeted J1043 as part of the main ELM Survey (Brown et al. 2012). A single spectrum obtained in 2014 April identified J1043 as a likely low-mass WD; a pair of spectra obtained in 2016 February revealed J1043 is velocity variable. We re-observed J1043 with time-series spectroscopy in 2016 December and 2017 March. The year-long observing time baseline for both objects provide strong orbital period constraints using radial velocity alone.

2.2. Spectroscopy

We obtain spectra in the same way as described in previous ELM Survey papers. In brief, we use the 6.5 m MMT telescope Blue Channel spectrograph with the 832 l mm\(^{-1}\) grating in second order, providing us with 1 Å spectral resolution over 3600 < \(\lambda\) < 4500 Å. We pair all spectra with comparison lamp exposures for accurate wavelength calibration. We measure radial velocities with the cross-correlation package RVSAO (Kurtz & Mink 1998). We adjust exposure times to observing conditions, and we obtain median 35 km s\(^{-1}\) errors for J0822 using exposure times between 12 and 22 minutes. J1043 is a brighter target, and we obtain median 20 km s\(^{-1}\) radial velocity errors using exposures times between 6.5 and 9 minutes. We became concerned about the length of our exposure times after we discovered the velocities were phasing at \(\approx\)45 minute periods.

To properly sample the phase curves and validate the short orbital periods, we obtained 1.5 hr worth of back-to-back spectra for both objects at 2 Å resolution (with the MMT Blue Channel spectrograph 800 l mm\(^{-1}\) grating in first order) using half the normal exposure times. The radial velocity uncertainties are worse with this setup; however, the time series confirm the \(\approx\)45 minute periods.

In total, we obtained 20 spectra of J0822 and 31 spectra of J1043. Both objects are observed to be single-lined spectroscopic binaries, as seen in Figure 1. We tabulate the radial velocities in the data behind the figure of Figure 2.

2.3. High-speed Photometry

We obtained time-series photometry for J0822 and J1043 using the Apache Point Observatory 3.5 m telescope with the Agile frame-transfer camera (Mukadam et al. 2011) and the BG40 filter on the night of UT 2017 March 2. We use exposure times of 30 s for J0822 and 15 s for J1043, and we obtain total integrations of 68 minutes and 60 minutes, respectively. There is a 5.6 minute gap in the J0822 data due to an instrument problem.

We use standard IRAF\(^3\) routines to perform aperture photometry. We correct for transparency variations using two relatively bright comparison stars in the field of view of each WD. After detecting eclipses in J0822, we attempted additional follow-up on three different nights. All follow-up attempts were unfortunately lost to weather.

3. Analysis and Results

3.1. Stellar Atmosphere Fits

We perform stellar atmosphere fits in the same way as described in previous ELM Survey papers. In brief, we fit the summed, rest-frame spectra to a grid of pure hydrogen atmosphere models that span 4000 K < \(T_\text{eff}\) < 35,000 K and 4.5 < \(\log g\) < 9.5 (Gianninas et al. 2011, 2014, 2015) and that include the Stark broadening profiles from Tremblay & Bergeron (2009). J1043 has a temperature and gravity that require three-dimensional stellar atmosphere model corrections, which reduce the 1D parameters by 230 K and 0.23 dex (Tremblay et al. 2015). We present the corrected parameters in Table 1.

J1043 is also a DAZ WD that exhibits strong Ca II \(\lambda 3933\) and Mg II \(\lambda 4481\) absorption lines (Figure 1). The Ca II and Mg II lines show the same radial velocity variability as measured from the Balmer lines, and so must come from the WD. We and others regularly see Ca II in other \(\log g\) ≈ 6 ELM WD spectra (Brown et al. 2013; Kaplan et al. 2013). We mask the region around Ca II when doing the Balmer line fits.

\(^3\) IRAF is distributed by the National Optical Astronomy Observatories, which are operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.
We estimate WD mass and luminosity by matching the measured $T_{\text{eff}}$ and log $g$ to the ELM WD evolutionary tracks of Istrate et al. (2016). The tracks account for the effects of element diffusion and rotation mixing, beginning at the moment the progenitor detaches from the mass-transfer phase. Progenitor metallicity can have a significant impact on the hydrogen envelope mass, the number of thermonuclear shell flashes, and the resulting cooling time of the tracks (Althaus et al. 2015). Thus, we apply $Z = 0.02$ tracks to disk objects and $Z = 0.001$ tracks to halo objects. As a cross-check, we compare with Althaus et al. (2013) solar metallicity tracks.

We interpolate the evolutionary tracks in the same way as described in previous ELM Survey papers. Our approach is to identify the two nearest tracks to an observed $T_{\text{eff}}$ and log $g$ value and to interpolate between the tracks on the basis of log $g$. Loops due to shell flashes complicate the picture, and so we re-sample $T_{\text{eff}}$ and log $g$ with their errors to estimate the dispersion of the mass and luminosity estimates. The results are presented in Table 1.

J0822 has a mass of $M_e = 0.304 \pm 0.014 \ M_\odot$ and an absolute g-band magnitude of $M_g = -9.96 \pm 0.09$ based on Istrate et al. (2016) $Z = 0.001$ tracks. With a de-reddened apparent magnitude $g_0 = 20.198 \pm 0.023$, J0822 is at a distance of 1.11 kpc and is likely a halo object (see below). J1043, on the other hand, has $M_e = 0.183 \pm 0.010 \ M_\odot$ and $M_g = +10.23 \pm 0.11$ mag based on Istrate et al. (2016) $Z = 0.02$ tracks. With a de-reddened apparent magnitude $g_0 = 19.054 \pm 0.017$, J1043 is at a distance of 0.58 kpc and is likely a disk object (see below). Mass and luminosity estimates from Althaus et al. (2013) tracks agree to within 1σ for both objects; thus, the mass and luminosity estimates appear robust to the choice of evolutionary tracks.

Interestingly, the evolutionary tracks predict that J1043 has undergone multiple thermonuclear shell flashes, while J0822 has not. Istrate et al. (2016) argue that rotational mixing can keep metals visible at the surface of a WD for longer-than-expected periods of time after shell flashes. This prediction is consistent with the strong metal lines present in J1043 and absent in J0822.

### 3.3. Disk/Halo Kinematics

We use kinematics to determine whether the objects belong to the disk or the halo. The gravitational redshift corrections for J0822 and J1043 are $7.9 \pm 0.3$ and $3.3 \pm 0.2$ km s$^{-1}$.
respectively. The objects have comparable systemic radial velocities, $\gamma_{J0822} = 10.2 \pm 23.0$ km s$^{-1}$ and $\gamma_{J1043} = 31.7 \pm 4.6$ km s$^{-1}$, but different proper motions.

We obtain proper motions from the HSOY catalog (Altmann et al. 2017), a new proper motion catalog that uses Gaia Data Release 1 positions for its final epoch. While J0822 is not detected in all epochs, its proper motion $\mu_{J0822} = 29.7 \pm 7.9$ mas yr$^{-1}$ is formally significant. J1043 is detected in all epochs and has a smaller proper motion, $\mu_{J1043} = 8.5 \pm 3.6$ mas yr$^{-1}$.

We calculate velocities in the Galactic rest frame assuming a circular velocity of 235 km s$^{-1}$ and the Local Standard of Rest motion of Schönrich et al. (2010). We use Chiba & Beers (2000) velocity ellipsoid values to put the motions in context. J0822’s space motion, $(U, V, W) = (8 \pm 25, -141 \pm 31, -29 \pm 28)$ km s$^{-1}$, falls outside the 2σ velocity dispersion threshold of the thick disk, but lies well within the 1σ velocity dispersion threshold of the halo. On this basis, we identify J0822 as a likely halo object. J1043’s space motion, $(U, V, W) = (-20 \pm 7, -6 \pm 7, 24 \pm 6)$ km s$^{-1}$, is consistent with the disk, and so we consider J1043 a likely disk object.

### 3.4. Binary Orbital Elements

We calculate orbital elements in a similar way as described in previous ELM Survey papers. In brief, we minimize $\chi^2$ for a circular orbit following the code of Kenyon & Garcia (1986). To compare the model to the observations, we average the model over each exposure time as we search through period and phase. The time baseline and phase coverage of the observations (Figure 2) yield a well-defined $\chi^2$ minimum in both objects. We determine the best-fit parameters from the envelope of the $\chi^2$ minima, which are symmetric but have substructure due to our sampling. The orbital fits to J0822 and J1043 have a reduced $\chi^2$ of 1.06 and 1.17, respectively.

We estimate errors by re-sampling the velocities with their errors and re-fitting the orbital parameters 10,000 times. This Monte Carlo approach samples the $\chi^2$ space in a self-consistent way. We report the median orbital parameters along with the errors and re-sampling uncertainties, given the distance $R_e$ and the Local Standard of Space motion, $\sigma_v$.

Kepler’s third law, written as the binary mass function, relates orbital period $P$, semi-amplitude $k$, ELM WD mass $M_1$, companion mass $M_2$, and orbital inclination $i$ as follows:

$$\frac{P^3}{2\pi G} = \left(\frac{M_2}{M_1 + M_2}\right)^2 \sin^3 i,$$

We directly measure $P$ and $k$. We derive $M_1$ from the observed $T_{eff}$ and log $g$. Given a constraint on $i$ (i.e., from eclipses or another observational constraint), we can derive $M_2$.

J0822 has $P = 40.28 \pm 0.23$ minutes and semi-amplitude $k = 415.7 \pm 22.7$ km s$^{-1}$. Assuming inclination $i = 88.1^{+1.5}_{-2.3}$ deg (see below), Kepler’s third law tells us that J0822’s unseen companion has a mass of $M_2 = 0.524 \pm 0.05 M_\odot$ and an orbital separation of $a = 0.364 \pm 0.008$ R$_\odot$. J0822 is a double WD binary. The gravitational-wave merger time of the binary is remarkably short, $\tau = 20 \pm 2$ Myr, however the gravitational-wave strain is only $\log h = -22.36 \pm 0.05$ given the distance and masses involved. The eclipse light curve allows us to further characterize J0822 below.

J1043 has $P = 45.65 \pm 1.32$ minutes and $k = 115.2 \pm 6.8$ km s$^{-1}$. The larger-period uncertainty reflects the broader envelope of its $\chi^2$ minimum. In the absence of a constraint on inclination, Kepler’s third law tells us that J1043’s unseen companion must have a mass of $M_2 > 0.07 M_\odot$ and an orbital separation of $a > 0.27 R_\odot$. However, we can rule out a low-mass companion on observational and physical grounds.

The radial velocities, taken alone, allow for a low-mass M dwarf or perhaps a brown dwarf companion, like the recently discovered eclipsing system J1205–0242 (Parsons et al. 2017; Rappaport et al. 2017). However, an M dwarf should fill the Roche lobe at this orbital separation. We see no evidence of mass-transfer. An M dwarf should also outshine the WD at infrared wavelengths. We compare publicly available GALEX ultraviolet, SDSS optical, and UKIDSS infrared photometry to the synthetic WD spectral energy distribution and find good agreement with the WD model and no evidence for infrared excess. The close orbital separation and lack of evidence for an M dwarf companion suggest that J1043 is a double-degenerate binary.

#### 3.4.1. Gravitational-wave Detection

Double-degenerate binaries like J1043 are mHz sources of gravitational waves. The strongest sources of gravitational waves in the mHz frequency range will be directly detected by LISA. We use the detection calculations of Korol et al. (2017) to estimate the signal-to-noise ratio ($S/N$) at which J1043 might be detected by LISA. The signal amplitude is proportional to the gravitational-wave strain of a binary times the LISA detector pattern function. J1630+4233, a previously discovered ELM WD binary that has an orbital frequency nearly identical to J1043 (Kilic et al. 2011b), provides an appropriate comparison. Korol et al. (2017) predict that LISA will detect J1630+4233 at $S/N = 5$ in 5 years of operation.

J1043’s gravitational-wave strain is identical to J1630+4233 if J1043 has $M_2 = 0.38 M_\odot$. Thus, LISA will detect J1043 at $S/N = 5$ in 5 years of operation if its mass ratio is $M_1/M_2 = 1:2$. Re-calculating the gravitational-wave strain for different mass ratios, LISA will detect J1043 at $S/N = 3$ if its mass ratio is $1:1$ and at $S/N = 9$ if its mass ratio is $1:5$. J1043 is a detectable gravitational-wave source for even the most pessimistic 1:1 mass ratio.

Although we do not measure the mass ratio, we expect that a degenerate companion should be more massive than the observed low-mass WD. ELM WDs are understood to be the result of double-common-envelope evolution, in which the ELM WD evolves last (Webbink 1984; Iben 1990; Marsh et al. 1995). The universe is not old enough to evolve a single star into an ELM WD. Indeed, eclipsing binaries in the ELM Survey with well-determined parameters have measured mass ratios between $M_1/M_2 = 1:2$ and 1:5 (Brown et al. 2011; Kilic et al. 2014b).

We conclude that J1043 is a likely LISA verification binary. To simplify the remaining discussion, we will assume that J1043’s companion has the average mass found in the rest of the ELM Survey, $M_2 = 0.76 \pm 0.25 M_\odot$ (Andrews et al. 2014; Boffin 2015; Brown et al. 2016a), and thus a mass ratio of $M_1/M_2 = 1:4$. This choice of $M_2$ corresponds to an orbital inclination of $i = 12.6^{+2.3}_{-1.8}$, a gravitational merger time of $\tau = 34^{+12}_{-7}$ Myr, and a gravitational-wave strain of $\log h = -21.7 \pm 0.1$. Future gravitational-wave measurements will tell us the exact answer.
limit, where for J0822 is about 2 mag deep and ≈60 s long eclipses every 40.5 minutes, statistically identical to the orbital period derived from the radial velocity data. We do not detect the secondary star. J0822 is faint, with apparent magnitude 20.34 mag, and its photometry is relatively noisy, with ±0.04 mag errors. Because we have only four data points during the primary eclipse, the Fourier transform of J0822 (bottom panel) does not show significant variability above the 3σ limit, where (A) is the average amplitude up to the Nyquist frequency. The relativistic beaming effect should produce 0.35% variations at the orbital period (Shporer et al. 2010), but this is also lost in the noise in our data. Tidal distortions are not significant in J0822. The oblateness of the low-mass WDs is predicted to be 0.3%, and the predicted amplitude of the ellipsoidal variations is ∼10⁻⁴, which we are unlikely to detect with ground-based observations.

The light curve and the Fourier transform for J1043 do not show any significant variability down to the 3σ limit of 0.8%. The absence of eclipses provides us with an upper limit on the inclination of the system, i ≲ 85°. Given the unknown inclination, the expected amplitudes of the relativistic beaming effect and ellipsoidal variations are ≤0.3% and ≤0.15%, respectively. If present, these photometric signals are also lost in the noise in our observations.

We model the light curve of J0822 using JKTEBOP (Southworth et al. 2004). We use the wavelength response of the BG40 filter from Hallakoun et al. (2016) and the linear limb-darkening coefficients from Gianninas et al. (2013) to calculate the limb-darkening coefficients. We adopt gravity-darkening coefficients of 0.36 for both the primary and secondary stars. We expect convection to be present in both stars, so adopting β = 0.36 is reasonable. Given how sparsely our data sample the primary eclipse, we avoid using more complicated limb-darkening laws. The orbital period and the mass ratio of the system are well-constrained by the radial velocity data. We thus fix the orbital period, mass ratio, and limb- and gravity-darkening coefficients when fitting for the inclination and component radii.

3.5. Eclipse Light Curve

Figure 3 presents the light curves for J0822 and J1043. J0822 shows 0.2 mag deep and ≈60 s long eclipses every 40.5 minutes, statistically identical to the orbital period derived from the radial velocity data. We do not detect the secondary eclipse. J0822 is faint, with apparent magnitude 20.34 mag, and its photometry is relatively noisy, with ±0.04 mag errors. Because we have only four data points during the primary eclipse, the Fourier transform of J0822 (bottom panel) does not show significant variability above the 3σ limit, where (A) is the average amplitude up to the Nyquist frequency. The relativistic beaming effect should produce 0.35% variations at the orbital period (Shporer et al. 2010), but this is also lost in the noise in our data. Tidal distortions are not significant in J0822. The oblateness of the low-mass WDs is predicted to be 0.3%, and the predicted amplitude of the ellipsoidal variations is ∼10⁻⁴, which we are unlikely to detect with ground-based observations.

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for J0822 will thus likely result in a merging event within 1–5 Myr. A reliable measurement of $\dot{P}$ for J0822 will thus likely require a 5–10 year time baseline.

4. Discussion

4.1. Eclipsing Double WD Binaries

There are now seven detached, eclipsing double WD binaries known whose WD masses are directly measured. An obvious question is what happens when these double WD binaries undergo mass-transfer. Total mass is important for whether the binaries are close enough to undergo stable mass-transfer and binary mass ratios are important for determining the evolutionary path of the system. Short-period WD binaries are sensitive to model assumptions about the stability of mass-transfer and double common-envelope evolution (Toonen et al. 2014). This has implications for the likely outcomes of the mergers.

Binaries composed of He+CO WDs with mass ratios $M_1/M_2 < 0.2$ should experience stable mass-transfer (Marsh et al. 2004) and evolve into AM CVn systems, a class of ultracompact binaries that consist of a WD accretor and a helium donor star (Nelemans 2005; Solheim 2010). The three eclipsing binaries with $M_1 < 0.2 M_\odot$ will likely evolve in this route.

He+CO WD binaries with mass ratios greater than about $M_1/M_2 > 0.5$ should experience unstable mass-transfer (Marsh et al. 2004) and merge into single objects like R CrB stars (Webbink 1984; Iben 1990). The four eclipsing binaries with $M_1 > 0.25 M_\odot$ will likely evolve into single $\sim 0.8 M_\odot$ objects.

4.2. Merger Rate of Double WD Binaries

As we state above, finding double WD binaries that merge on $\sim 10$ Myr timescales implies many more such binaries must have formed and merged over the age of the Milky Way. In Brown et al. (2016b), we show that the distribution of ELM WD binaries in our magnitude-limited sample implies an ELM WD merger rate of $3 \times 10^{-3}$ yr$^{-1}$ in the Milky Way disk. The major source of uncertainty comes from the small number statistics of rapidly merging binaries like J0822 and J1043. While J0822 formally falls outside the ELM Survey color and magnitude limits, J1043 is very much a part of the sample. Assuming the prior on its secondary, J1043 ranks as the fifth shortest merger time system in the ELM Survey after J0651, J0935, J1630, and J0106 (Figure 6).
Unstable mass-transfer is only expected for near-unity mass ratios. However, Marsh et al. (2004) show that there remains a large region of parameter space in which the stability of mass-transfer is ambiguous, in which stability depends primarily on the strength of spin–orbit coupling. When the donor ELM WD fills its Roche lobe, the accretor spins up due to the incoming matter stream. Weak spin–orbit coupling means the accretor is unable to transfer angular momentum back to the orbit of the donor on a fast enough timescale. The result is that the binary orbit shrinks, mass-transfer rate grows, and mass-transfer becomes unstable. Alternatively, the initial phase of hydrogen mass-transfer may generate nova-like outbursts that drive He +CO WD systems into merger (Shen 2015). Either way, the merger rate of observed short-period ELM WD binaries like J1043 demands that mass-transfer in most He+CO WD binaries is unstable.

5. Conclusions

We present the discovery of a detached eclipsing 40 minute orbital period double WD binary and a detached 46 minute orbital period double WD binary. These two systems bring our targeted ELM Survey sample to 82 WD binaries. The two new systems, SDSS J082239.546+304857.19 and SDSS J104336.275+055149.90, have gravitational-wave merger times of 20 Myr and ∼34 Myr, respectively. J0822 is a detached, eclipsing double WD binary. J1043 is a likely gravitational-wave verification binary.

We revisit the ELM WD binary merger rate and find that the new discoveries affirm our previous result: observed He+CO WD binaries merge at a rate at least 40 times greater than the formation rate of stable mass-transfer AM CVn systems, and so the majority must merge into single objects like R CrB stars (Brown et al. 2016b). The implication is that spin–orbit coupling in He+CO WD mergers is very weak (Marsh et al. 2004), or else nova-like outbursts during the initial phase of mass-transfer drive the systems into merger (Shen 2015).

Eclipsing double WD binaries are especially well-constrained systems. Yet, J0822 and the other six known eclipsing binaries do not contain a single “normal” 0.6 $M_\odot$–0.7 $M_\odot$ WD. While four eclipsing binaries have expected mass ratios of 1:1 to 1:2, three have extreme 1:5 mass ratios in tension with binary population synthesis models. Finding and characterizing eclipsing WD binaries like J0822 is important for better understanding WD binary evolution and constraining the final outcome of WD binary mergers.

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Facilities: MMT (Blue Channel Spectrograph), ARC (Agile Camera).

Software: IRAF (Tody 1986, 1993), RVSAO (Kurtz & Mink 1998), JKTEBOP (Southworth et al. 2004).

Figure 6. Gravitational-wave merger time vs. mass ratio for double WD binaries in the ELM Survey with $\tau < 100$ Myr. Each dot represents a Monte Carlo calculation accounting for observational uncertainties plus constraints on inclination (i.e., eclipses). J0822 is drawn in red, and J1043 is drawn in blue.
