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A Catalog of Potential Post–Common Envelope Binaries

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Abstract

We present a catalog containing 839 candidate post–common envelope systems. Common envelope evolution is very important in stellar astrophysics, particularly in the context of very compact and short-period binaries, including cataclysmic variables, as progenitors of, e.g., supernovae Type Ia or mergers of black holes and/or neutron stars. At the same time, it is a barely understood process in binary evolution. Due to limitations, since partially remedied, on direct simulation, early investigations were mainly focused on providing analytic prescriptions of the outcome of common envelope evolution. In recent years, detailed hydrodynamical calculations have produced deeper insight into the previously elusive process of envelope ejection. However, a direct link between the observations and theory of this relatively short-lived phase in binary evolution has not been forthcoming. Therefore, the main insight to be gained from observations has to be derived from the current state of systems likely to have gone through a common envelope. Here we present an extensive catalog of such observations as found in the literature. The aim of this paper is to provide a reliable set of data, obtained from observations, to be used in the theoretical modeling of common envelope evolution. In this catalog, the former common envelope donor star is commonly observed as a white dwarf or hot subdwarf star. This catalog includes period and mass estimates wherever obtainable. Some binaries are borderline cases to allow an investigation of the transition between a common envelope formation and other mass-transfer processes.

Unified Astronomy Thesaurus concepts: Catalogs (205); Common envelope binary stars (2156); Stellar masses (1614); Close binary stars (254); White dwarf stars (1799); Subdwarf stars (2054); Common envelope evolution (2154); Eclipsing binary stars (444); Spectroscopic binary stars (1557); Cataclysmic variable stars (203)

Supporting material: machine-readable table

1. Introduction

Observations of stellar remnants such as white dwarfs (WDs) in close binary systems pose challenging questions for the theory of binary evolution. Most notably, cataclysmic variables (CVs), in which a WD accretes mass at low rates from a hydrogen-rich companion, have orbital separations much smaller than would have been needed to accommodate the WD's progenitor star. This suggested the possibility of a common envelope (CE) phase of evolution, in which the envelope of a star that has come to fill its Roche lobe expands to encompass the binary companion (Paczynski 1976). This results in a significant reduction of the binary's orbital separation. If a binary does not merge in the course of CE evolution, the shared envelope is ejected. Although many additional types of close binaries, some including neutron stars (NSs) or black holes (BHs), have since been suggested as possible CE survivors, the physics of CE evolution is still not well understood. Solving this mystery will be important, because CE evolution appears to provide the favored viable pathway to the formation of close binaries outside of dense stellar environments that may result in supernovae (SNe) Type Ia (e.g., Han et al. 1995; Ruiter et al. 2009; Mennekens et al. 2010; Toonen et al. 2012; Claeys et al. 2014; Ablimit et al. 2016) or mergers of NSs and/or BHs (e.g., Bloom et al. 1999; Belczynski et al. 2002; Voss & Tauris 2003; Dominik et al. 2012; Mennekens & Vanbeveren 2014; Eldridge & Stanway 2016; Stevenson et al. 2017; Kruckow et al. 2018; Mapelli et al. 2019; Klencki et al. 2021, and many more).

The CE phase has remained inaccessible to direct observation. Although there are candidates (e.g., Ivanova et al. 2013a; MacLeod et al. 2017), confirmation is challenging. The CE is expected to have observable characteristics similar to those of a giant, with its photosphere hiding the binary. Because the phase probably lasts about 10^3–10^5 yr, it is not possible to track the evolution of the envelope or the binary within. However, many close binaries could be CE end states. After the ejection of the CE, at least one stellar component should be hydrogen-depleted and thus observable as, e.g., a WD or a subdwarf O/B star. The ejected CE material is expected to cool and become dim enough to be inaccessible to direct observations. Similarly, a compact remnant will cool and become less luminous if no further nuclear burning takes place. The quintessential example is CVs, although they have evolved through tidal interactions and mass transfer and do not, therefore, represent pure CE end states.

During recent years, a large number of possible systems, which are believed to have gone through a CE phase, have been identified. Observations usually focus on individual systems or specific types of stars (see references in Table 3). Recently, major observational efforts have gone into campaigns that resulted in better characterizations of different types of stellar objects, including potential CE products (e.g., Patterson et al. 2005; Heller et al. 2009; Geier et al. 2010b; Nebot Gómez-Morán et al. 2011; Zorotovic et al. 2011; Copperwheat et al. 2011a; Gianninas et al. 2014; Kupfer et al. 2015a; Brown et al. 2016a; van Roestel et al. 2018, and several more). We have compiled a "unified" catalog of post-CE candidates to combine systems from different observational campaigns and individual observations into a single data set that will serve as a tool of theoretical investigations on the general mechanisms of the CE phase.

A theoretical prescription based on the conservation of energy was proposed by Webbink (1984) and de Kool (1990): the so-called α formalism. This commonly used prescription allows a prediction of the CE end state and has become more complex in recent years when taking more energy sources and sinks into account (e.g., Kruckow et al. 2016). An alternative prescription making use of angular momentum conservation was introduced by Nelemans et al. (2000), the so-called γ formalism, to explain systems that show only a marginal inspiral. For a more comprehensive summary of the CE phase, we refer the reader to Ivanova et al. (2013b, 2020). In recent years, hydrodynamic simulations have become powerful enough, enabling simulations of the CE phase in greater detail and becoming more and more successful in ejecting the CE. As these simulations require significant computational resources, they only tackle a small number of cases with limited sets of initial parameters (e.g., Passy et al. 2012; Ricker & Taam 2012; Kramer et al. 2020; Sand et al. 2020).

This catalog is intended to provide a broad overview, several times larger than previous collections of post-CE binaries, of different systems. All binaries that have not evolved significantly after a CE should still exhibit signatures of the CE evolution. In Section 2, we introduce the catalog. First, we explain our selection of systems. This is followed by a short overview and a brief statistical summary of the parameters compiled in the catalog. At least a period and limits on the mass of the CE primary, the donor of the most recent CE, and its companion are required. We finish this section with a discussion of the limitations on the parameters derived from observations. In Section 3, we discuss the theoretical evolution of the systems. This includes different formation paths, the evolution of the system since the end of the CE, and their future. Finally, we give a short summary in Section 4. A shorthand version of the catalog can be found in Appendix A.

2. The Catalog

This is a catalog of binaries that are likely to have passed through a CE phase, leaving the binary in the presently observed state. The catalog contains data obtained from a large sample of different observations. This includes detailed spectroscopic observations, eclipsing light curves, nova events, and other observations. Individual literature sources for each system are given by the references in the catalog. We follow the guidance of the authors of each reference as to which values of the measured quantities are most reliable. In cases in which the authors presented several solutions without a preference, the system's note indicates the chosen model. The main goal is to provide a large database with the data needed for comparison to theoretical studies of CE evolution. This catalog represents an improvement on the number of systems of about an order of magnitude compared to earlier studies of CE theory (Nelemans & Tout 2005; De Marco et al. 2011; Iaconi & De Marco 2019).

The catalog can be used in different ways. First, it allows the use of a maximum-sized sample by combining different observations. This is the main benefit for theoretical uses of this catalog, since comparison to theoretical models requires a large enough sample size for proper statistical analysis. Further, calibration of empirical models requires a sufficient number of limiting cases, better provided by a large sample. Second, this catalog allows the user to use any given subsample by filtering according to specific properties that are of interest in a more detailed investigation of systems in a tight range of any parameter space of the collected quantities. Third, this catalog also provides samples of individual observational campaigns by filtering for the corresponding references to have a sample with the same observational biases, allowing systematic comparisons between different observational campaigns. Finally, this catalog provides a comprehensive and extensive literature inspection, including several references on individual systems for focused investigations from a theoretical standpoint.

For a theoretical investigation, an observational test sample needs to provide details about all systems that went through a certain evolution independent of their observational characteristics nowadays. At the same time, it should allow one to differentiate systems with similar current structure but different evolutionary history. In addition to this main discrepancy between theoretical needs and observational limitations, it is useful to reduce differences in observational biases, like selection biases, naturally introduced by using different instruments and/or analysis pipelines. Consequently, each comparison between theory and observations has to find a balance between statistical and systematic uncertainties by using an appropriate subsample of this catalog.

2.1. Data Selection

We identified an extensive set of about 10^3 papers reporting on systems that are possibly related to the CE. The selection criteria to finally list a system in the catalog can be summarized as: (1) the system contains a hydrogen-depleted component (that lost its envelope), and (2) the fundamental parameters of the system have been derived from observations and given in the literature. The aforementioned parameters are the period, $P < 100$ days (this cutoff should exclude most binaries, which had no or stable mass transfer), and estimates on the masses. Here we require at least a limit placed on both of the component masses. It should be noted, however, that the parameters provided in the catalog are not limited to these parameters pertaining to our inclusion criteria, as will be made abundantly clear in Section 2.2. Other parameters that could be useful for theoretical studies are also included.

Because a CE drains energy and angular momentum from its host binary, one common feature of all post-CE binaries is that their orbital separations are relatively small, smaller than expected from considerations of the size of the progenitor star. Speaking from an observational point of view, such binaries exhibit short orbital periods from minutes to days. A non-Roche-lobe-filling giant would suggest a binary orbit with a period of months or years. Additionally, there is at least one hydrogen-depleted component that is assumed to be the donor star in the mass-transfer phase leading up to the formation of the CE. This hydrogen-depleted component can be a degenerate object, like a WD or a helium-burning subdwarf. The latter ones usually show a spectral class of B or O stars, thus classified as sdB/O, while being more compact and less luminous compared to main-sequence (MS) stars.

We note that, for purposes of nomenclature, this study designates as the CE primary component the star that was most likely the donor of the CE. This is in contrast to most observational papers, which tend to designate the more luminous star as the primary. For some systems containing two WDs, it is not always clear which component is most likely the donor of the CE. We attempt to address this via some simple comparisons, e.g., making use of given cooling ages. We split the catalog into three main populations: double WDs (DWDs), WDs with a non-WD or unknown companion (WD+), and sdB/O binaries (sdB/O+). These are expected to differ most in terms of observational biases and are shown separately in the following. In sdB/O+WD binaries, the sdB/O star is most likely the younger star, which places them in the sdB/O+ sample instead of the WD+ sample. In the WD+ sample, the companion is usually noncompact and still a MS star.

The identity of a post-CE candidate is usually only inferred from its current structure and compactness. This catalog includes a note to indicate borderline cases of systems that may have formed through a different evolutionary channel; see Section 3.1.1. Binaries with an NS or BH as the remnant of the CE donor are not included in the catalog. The reason for this lies in the consideration that the formation of an NS or BH (i.e., SNe) is believed to expel a significant amount of mass and may impart a kick on the newly born components, changing the component masses and their orbits significantly. As a consequence, the signatures of the CE phase are not visible anymore, or are at least hidden from sight. The complex nature of SNe prevents a solid determination of the CE end state from current observations. In most cases, an inferred post-CE binary would be far from being constrained in a unique way.

We require the orbital period to be less than 100 days and a limit for both masses to be given in the literature in order to list an observed system in this catalog. Additionally, the system must contain a hydrogen-depleted component, the donor of a potential CE. A shorthand version of the catalog is given in Table 3, while the columns in the catalog are summarized in Section 2.2 and Table 2. Some statistical properties of the catalog are presented in Section 2.3. There are different sources of uncertainties and limitations on the observational side. The most common ones are summarized in Section 2.4.

2.2. Overview of the Systems and Their Recorded Quantities

The catalog contains a growing number of systems: 839 to date. The collected data include the name(s) of the system in the literature, several binary and stellar parameters, a flag (assigned by us and explained in detail in Sections 2.4.1, 3.1.2, 3.2.2, and 3.2.3), the reference(s), and, if required, an additional note, e.g., which values are used if the corresponding reference states several independent ones. All parameters in the catalog are given in the included references; only unit conversions are performed. Most parameters are presented with uncertainties. The uncertainty in the orbital period is usually very small and therefore omitted in the catalog. An overview of the numbers can be found in Table 1.

The binary parameters are the orbital period, P; mass ratio, q; semimajor axis, a; eccentricity, e; inclination, i; and cooling age of the system. The orbital period is recorded in days. In most cases, only one of the masses is directly inferred from the observations (or is assumed), while the second mass is obtained with a measurement on the mass ratio or function—a combination of the two masses and the inclination. The mass ratio is usually given by the velocity amplitudes of the two components. Hence, this parameter is often more reliable than the individual masses. The semimajor axis is generally calculated in the literature, e.g., using Kepler's third law, but sometimes it can be inferred from the distance in resolved binaries. Eccentricities are only calculated by modeling the orbit (generally via light-curve fitting) or simply assumed to be zero in the majority of the cases. If the inclination of the binary can be constrained from observations, it is used in the determination of the individual masses from the measured mass function. Hence, systems with a given inclination usually have tighter constraints on the individual component masses

Table 1
Overview of the Systems in the Catalog

Criterion	sdB/O+	DWD	WD+
All	185	123	531
Mass, M_1	$184^{\downarrow 49}_{\uparrow 51}$	$122^{\downarrow 96}_{\uparrow 96}$	$506^{\downarrow 389}_{\uparrow 411}$
Mass, M_2	$71^{\downarrow 72}_{\uparrow 181}$	$94^{\downarrow 75}_{\uparrow 117}$	$505^{\downarrow 449}_{\uparrow 450}$
Masses, M_1 and M_2	71	93	492
WD companion	126	123	0
sdB companion	1	0	0
MS companion	56	0	15
NS companion	6	0	45
BH companion	7	0	0
BD companion	6	0	24
M-type companion	35	0	164
K-type companion	2	0	34
G-type companion	1	0	11
F-type companion	0	0	42
A-type companion	0	0	26
Unknown companion (-)	2	0	170
No flag (-)	39	64	244
Mass transfer (MT)	2	1	22
Cataclysmic variable (CV)	0	0	223
Statistically (S)	0	56	20
Assumed WD mass (SWD)	0	0	82
Assumed sdB mass (SsdB)	140	0	0
Assumed mass ratio (Sq)	5	0	2
Assumed companion mass (SM2)	0	1	19
Triple (TRI)	1	1	7
Mass ratio, q	$40^{\downarrow 31}_{\uparrow 31}$	$67^{\downarrow 69}_{\uparrow 64}$	$376^{\downarrow 318}_{\uparrow 318}$
Semimajor axis, a	$34^{\downarrow 33}_{\uparrow 38}$	$62^{\downarrow 61}_{\uparrow 63}$	$184^{\downarrow 166}_{\uparrow 168}$
Eccentricity, e	$44^{\downarrow 44}_{\uparrow 13}$	$0^{\downarrow 3}_{\uparrow 0}$	$49^{\downarrow 44}_{\uparrow 40}$
Inclination, i	$63^{\downarrow 71}_{\uparrow 67}$	$27^{\downarrow 25}_{\uparrow 23}$	$291^{\downarrow 314}_{\uparrow 319}$
Radius, R_1	$51^{\downarrow 43}_{\uparrow 43}$	$69^{\downarrow 69}_{\uparrow 69}$	$209^{\downarrow 155}_{\uparrow 155}$
Radius, R_2	$37^{\downarrow 35}_{\uparrow 34}$	$19^{\downarrow 19}_{\uparrow 18}$	$333^{\downarrow 313}_{\uparrow 314}$
Effective temperature, $T_{\mathrm{eff},1}$	$167^{\downarrow 148}_{\uparrow 148}$	$120^{\downarrow 94}_{\uparrow 94}$	$296^{\downarrow 272}_{\uparrow 266}$
Effective temperature, $T_{\mathrm{eff},2}$	$35^{\downarrow 34}_{\uparrow 31}$	$35^{\downarrow 31}_{\uparrow 28}$	$167^{\downarrow 103}_{\uparrow 99}$
Luminosity, L_1	$18^{\downarrow 18}_{\uparrow 18}$	$0^{\downarrow 0}_{\uparrow 0}$	$21^{\downarrow 17}_{\uparrow 17}$
Luminosity, L_2	$10^{\downarrow 10}_{\uparrow 10}$	$0^{\downarrow 0}_{\uparrow 0}$	$21^{\downarrow 19}_{\uparrow 19}$
Surface gravity, $\lg(g_1)$	$161^{\downarrow 143}_{\uparrow 143}$	$102^{\downarrow 84}_{\uparrow 84}$	$223^{\downarrow 205}_{\uparrow 205}$
Surface gravity, $\lg(g_2)$	$16^{\downarrow 14}_{\uparrow 14}$	$16^{\downarrow 12}_{\uparrow 12}$	$109^{\downarrow 62}_{\uparrow 62}$
(Cooling) age	$5^{\downarrow 6}_{\uparrow 4}$	$61^{\downarrow 64}_{\uparrow 61}$	$86^{\downarrow 27}_{\uparrow 25}$
Gaia EDR3 ID	184	123	529
Distance from EDR3	183	121	520

Note. The columns are the main groups of systems considered here and provide counts for different criteria. The index 1 or 2 refers to the CE primary (the donor of the possible CE) and secondary component. The values behind ↑ and ↓ are the counts where the lower and upper limits of the quantity given by the criteria are available, respectively. The distances are calculated from the Gaia parallax. For more details, see text (Section 2.2).

than other systems. If the remnant of the CE donor, the CE primary WD in our catalog,[7] is well observed, a cooling age can be estimated from the models. This provides an estimated lower limit on the time since the end of the CE.

The stellar parameters are the mass, M_i; type; radius, R_i; effective temperature, $T_{\mathrm{eff},i}$; luminosity, L_i; and surface gravity, $\lg(g_i)$, where $i \in \{1, 2\}$ indicates the CE primary stellar component, the remnant of the CE donor, and its companion. In theoretical modeling, the masses of the stars are key parameters. Hence, only systems having at least a limit on both masses are considered in the catalog. But those masses are difficult to measure directly. For most systems, only a mass ratio can be directly obtained from the observational data. Only if the inclination is known can the masses be directly determined. Hence, some authors use limits on the inclination to constrain the most likely mass of an individual system, while others fit the brighter component to a theoretical model to estimate the mass, and some resort to simply assuming a mass. The types of the stars can be constrained in different ways. First, it could be a constraint arising from the brightness and compactness of a component. On the other hand, sufficiently bright stars may be assigned to a spectral type. The radii could either be inferred from some models when constraining the mass or directly observed in eclipsing systems. The effective temperature and surface gravity are usually constrained from fitting the spectrum. The luminosity is mostly estimated from a distance measurement of the system and was only rarely available at the time the source papers were written.

For most systems, at least some of the parameters are not given in the literature. Table 1 provides an overview of how many systems in the catalog fulfill a certain criterion. The data are split into the main groups of systems in the catalog: DWDs, WD+, and sdB/O+. First, an overall count is given. In the second block, the availability of the mass values is checked; all systems have at least an upper or lower limit for both masses, if not a value itself. Third, the different companion types are listed: a WD, an MS star, an NS, a BH, or a brown dwarf (BD), or the spectral type is given. Here "unknown" refers to having no information about the companion in the cited reference(s). Some systems have two to three open possibilities; hence, the sum of this block may exceed the total number of systems.

Fourth, depending on the circumstances, some systems ought to be excluded from certain studies conducted using our database and are therefore marked by different flags denoting the potential reasons for exclusion in each case. The first two flags are about observational features of binary interaction; for more details, see Sections 3.2.2 and 3.2.3. All of the flags starting with an "S" are related to assumptions about the masses; see Section 2.4.1. The last flag is about the possibility of a different nature of the system, e.g., in a triple system; see Section 3.1.2. Fifth, the availability of other parameters is checked. Finally, the success with a cross-match to Gaia EDR3 data[8] is shown. Most of our systems are found in the Gaia EDR3, except for those only detected by other bands than optical, hence having no Gaia ID. The majority of the Gaia objects are detected at different epochs with Gaia and therefore have measured parallax values (Gaia Collaboration et al. 2020). The distance estimates in the catalog are calculated from this parallax; see Section 2.4.3.

2.3. Catalog Statistics

Figure 1 provides an overview of the systems in the catalog. See Appendix B (Figures 8, 9, and 10) for the three subpopulations sdB/O+, DWD, and WD+ binaries individually. The cumulative distributions of the masses (Figures 1(h) and (i)) show a few jumps that are caused by the assumed values where they cannot be measured directly; see Section 2.4.1. The secondary masses cover a large range and do not show any preferences for systems where the masses are measured. Here small accumulations at specific masses are caused by fits to stellar model grids, where the closest model is assigned to the observed star. Beside assumed masses, the CE primary masses show an overabundance at masses $\lesssim 0.2\,M_\odot$, which is caused by a large sample of binaries from an ELM survey (Brown et al. 2016a); see Figure 2(a). All sdB stars are generally accepted to possess masses higher than $0.3\,M_\odot$, as lower-mass objects are unable to meet the conditions required for helium ignition (Kippenhahn et al. 2012). These lower-mass objects will therefore immediately thermally contract to become He WDs. Shortly after their progenitor cores are exposed, such proto-WDs still look similar to sdB stars. There are very few stars below $0.3\,M_\odot$ classified as sdBs in the literature. Usually, WDs, especially low-mass ones, are very faint and therefore difficult to observe.

The relation of the black circles visible in Figure 1(g) is mainly following Kepler's third law; see green dots. Hence, it shows a slope of 2/3 on a logarithmic scale. The spread of the relation is caused by the different total masses of the binaries. As a consequence, the period and semimajor axis plots (Figures 1(c) and (d) versus Figures 1(e) and (f)) show similar distributions of the systems, with the main difference being that certain systems, for which semimajor axis values are not available, are absent from the corresponding plots. It should be noted that the systems having a BD as a companion look like a natural extension of the binaries with hydrogen-burning stars with a mass above $0.08\,M_\odot$.

Both the period (Figure 1(j)) and the semimajor axis distribution (Figure 1(b)) show a change in the slope at about $0.06\,\mathrm{day} \approx 1.4\,\mathrm{hr} \approx 90\,\mathrm{minutes} \approx 5000\,\mathrm{s}$. This can be interpreted as the range where systems decay via gravitational-wave radiation (GWR) at a similar rate as such systems are created. Nearly all systems below the aforementioned limit of about 0.06 day are DWD or sdB/O+WD binaries; see Figure 2(i). Hence, this gives a second interpretation of that limit to be the limiting case for hydrogen-rich companions to fill their Roche lobe and initiate mass transfer in the post-CE system and become CVs; see Section 3.2.3. Additionally, it should be noted here that DWD and sdB/O+WD binaries may have experienced more than one CE phase during their prior evolution.

The tightest binaries are DWD systems, as one would expect. The binaries with the shortest periods in the WD+ sample have either undetermined or NS companions. More massive WDs have smaller radii. Hence, it would be expected that the tightest orbits short of a merger event of two WDs are only reachable for massive WDs. In the catalog, the tightest DWD binaries contain intermediate-mass WDs, perhaps indicating some biases in the collected sample. The distributions for the CE primary star—the donor star of the potential CE—do not show such clear trends. For some reason, the DWD systems show a significantly lower average mass of the CE primary than the systems having any other companion to

[7] In DWDs, the CE primary WD is the younger one.
[8] https://www.cosmos.esa.int/web/gaia-users/archive

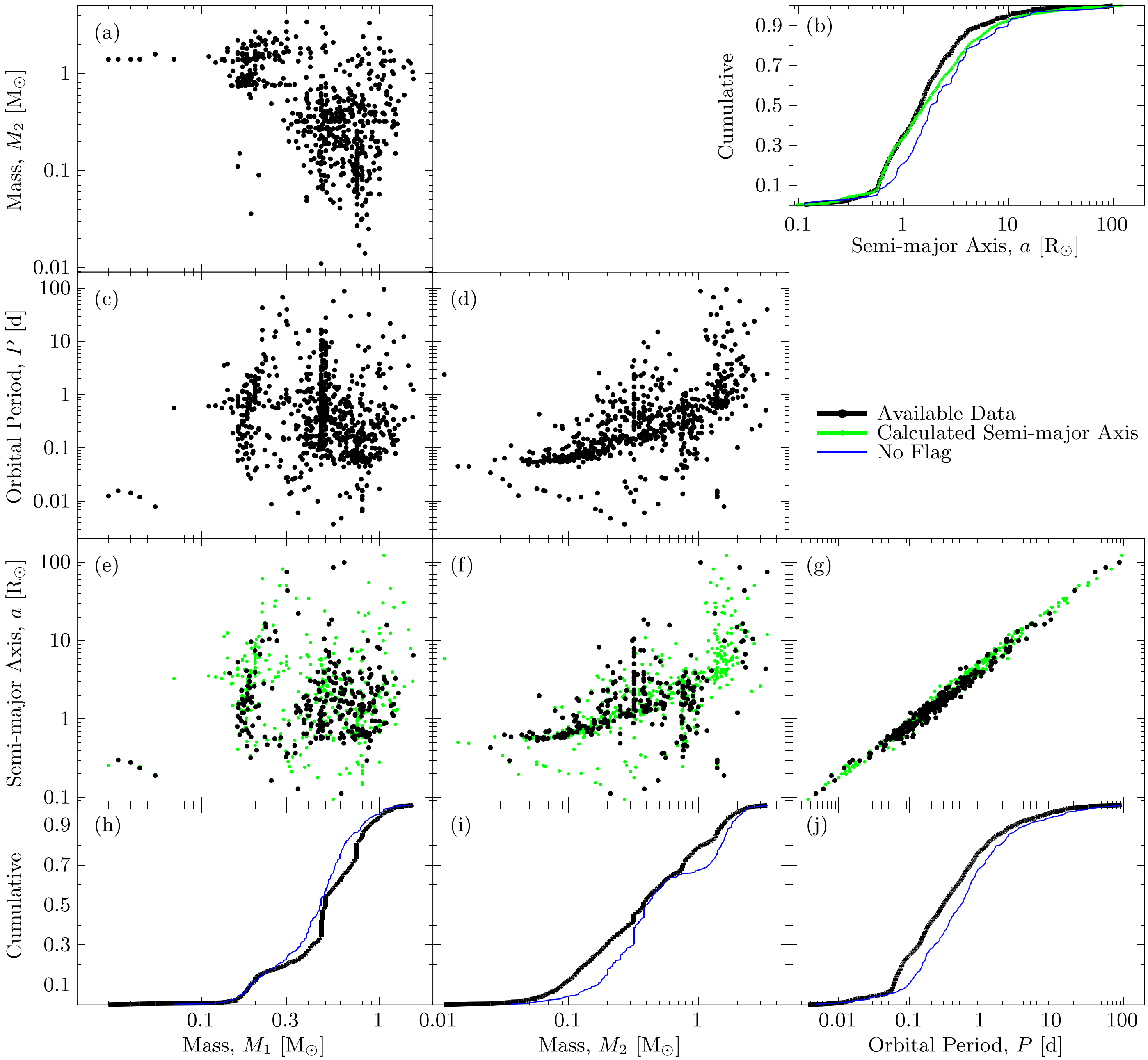

Figure 1. Masses, periods, and semimajor axes of the systems in the catalog. We show the cumulative distributions at the bottom of each column, i.e., panels (h)–(j). The thick black lines represent the full sample, while the thin blue lines exclude all systems with a flag. We show the cumulative distribution of the semimajor axes in the top right corner (panel (b)). Additionally, it contains a green line of medium thickness for values calculated with Kepler's third law. We note that the discrepancy in the number of systems is caused by missing values in the catalog. For clarity, we omit error bars in this figure. Figure 3 shows panel (a) including the observational uncertainties. See Section 2.3 and Appendix B for more details.

the CE primary WD. It is probably related to the fact that the less massive WD usually forms later than the more massive one, hence being the donor of the most recent mass transfer.

From Figure 2, it is evident that the three main groups we differentiate here cover different ranges in most of the parameters collected in the catalog. The sdB/O stars cover a smaller mass range than the WDs. The WDs can have lower masses because those stars are too low in mass to become sdB/Os and directly cool to become WDs after they have lost their envelope. In principle, sdO stars may have masses similar to or even larger than WDs, but here the observational sample is biased by the shorter lifetime of massive sdO stars, which makes them less common. In the sdB/O+ and WD+ sample, most companions are low-mass MS stars; hence, these distributions in Figure 2(b) look very similar. The DWD population differs here because the companion is the first formed and usually more massive WD, but it is classified in the catalog as the CE secondary. This is confirmed by the mass ratio distribution.

The radius distributions resemble the known relations; see Figures 2(d) and (e). First, the most massive WDs are the most compact. Second, WDs are more compact than sdB/O stars. Third, BDs have a similar size as sdB/O stars. In this sample (as would be expected), hydrogen-burning stars have the physically largest radii. There are barely any giant like stars in the sample, as they require a longer orbital period. Similarly,

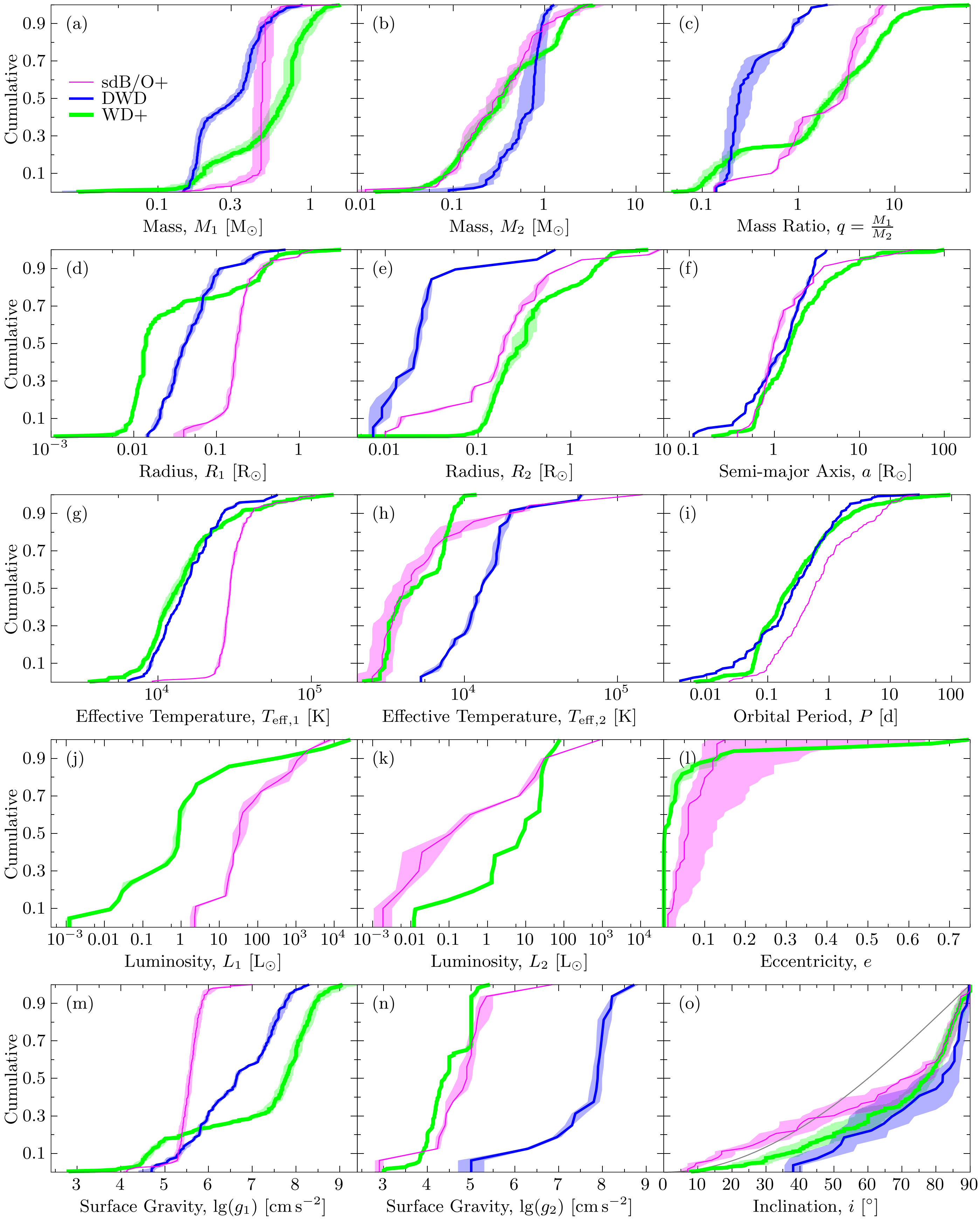

Figure 2. Cumulative distributions of the different catalog parameters. Color and line thickness indicate the binary type according to the key in panel (a). The corresponding counts of systems can be found in Table 1. The gray line in panel (o) indicates the distribution of random inclinations. To show the uncertainty contours, missing uncertainty values are assumed to be the geometric mean of the recorded ones.

sdB/O stars are hotter than WDs, while low-mass MS stars and BDs are the coolest stars in the sample; see Figures 2(g) and (h). Again, such trends are visible in the surface gravity; see Figures 2(m) and (n). Massive WDs are most compact, hence having the highest surface gravity. Next in line are the low-mass WDs and the sdB/O stars, which have lower surface gravity, followed by the MS stars and BDs, which have the lowest surface gravity of them all.

The differences in the distribution of the inclination (Figure 2(o)) is probably caused by observational biases. Eclipsing systems allow better constraints on the system's parameters from the observations. Additionally, the projected velocities are larger and therefore easier to observe. It is evident that this observational selection effect impacts the three main subpopulations differently. Most systems have low eccentricities (see Figure 2(l)) or are assumed to be circular due to their short periods. Additionally, some eccentricity effects have only small imprints in the observations, hence eccentricity values are omitted in most observational papers.

Figure 6(a) shows the cumulative distribution of the cooling ages of the CE primary star, which corresponds to a lower limit of the time since the end of the CE. We do not show the distribution for the sdB/O+ category, since it contains only five systems. These five systems show very short cooling ages. The WD+ systems tend to be younger than DWD systems, which is probably due to the smaller secondary mass M_2. Although half of the DWD systems are older than 1 Gyr, the age distribution peaks at a much younger age than predicted in a model of single stars; the gray line shows the predicted WD age distribution in the galactic chemical evolution model for the solar neighborhood (Kobayashi et al. 2020), where the metallicity-dependent stellar lifetimes and upper limits of carbon–oxygen WDs are assumed but no binary effects are included. In binaries, the companion stars could cause the young ages of WDs. We should also note that the initial mass–to–final mass relation, and hence the stellar lifetimes of both stars, can be different. It is also possible that some DWD systems have merged and exploded as Type Ia SNe; see Section D. Hence, it is expected that the observed distributions are different from the model line.

2.4. Observational Limitations

We can observe the stars only as we can see them with our telescopes from Earth. Hence, there are limitations on the information we get. Often we cannot resolve binaries, especially the tight ones in this catalog. The observed light is therefore a combination of the emission of the two components. This causes the problem that the information of the dimmer star is hidden in the light of the brighter one.

To get information on the tightly orbiting masses, a system needs to either be eclipsing or show clear spectral lines, preferentially for both stars. The catalog systems show an overabundance of eclipsing systems—$i \approx 90°$; see Figure 2(o). To get a spectrum of a faint star or binary, a certain integration time is required. This becomes problematic when this integration time covers a longer part of the orbit and therefore leads to line broadening by averaging over different orbital phases. Additionally, spectroscopic surveys do not revisit binaries often enough to get a good orbital coverage to constrain the orbital period well.

2.4.1. Statistically Inferred and Assumed Mass Values

Often, the required theoretical quantities cannot be directly inferred from the observation. Some values are assumed in order to make full use of information about observational knowledge of combinations of quantities. One of the most prominent cases is the observable mass function that relates the masses with the usually unknown inclination. The inclination enters as a geometrical effect and therefore as $\sin(i)$ and powers of it. The limitation of the trigonometrical functions in a Euclidean space allows one to determine limits on the masses. The limit is usually a lower limit on the mass via $\sin(i) \leqslant 1$.

If the orientation is isotropic, the most likely inclination is 60°. Some observational papers use this to determine the detailed mass values of an individual system to be the most likely. In some cases, the observations allow the exclusion of some inclinations; hence, the most likely value is then determined with Monte Carlo techniques (e.g., Brown et al. 2016a). Those cases are marked in the catalog with the flag for statistical determination of the values (S).

The mass ratio is the most fundamental quantity that is usually determined by spectroscopic observations. It is directly related to the relative velocity of the two components. For eclipsing binaries, the mass ratio can be determined as well. Hence, most observations will provide a good measurement of the mass ratio. It is a bit trickier to get individual masses. Here different approaches are used, e.g., the previously mentioned mass function, when the inclination can be determined. On the other hand, the masses can be determined via the total mass of the binary, $M_1 + M_2$. One way to determine the total mass uses the distance of a resolved system, which provides an independent measurement of the semimajor axis and a total mass via Kepler's third law. To resolve a system, the orbital separation usually needs to be wider. Hence, sometimes for those systems, the mass ratio is uncertain and, consequently, in rare cases, even set to a certain value; in the catalog, these are marked with a flag (Sq).

Another common way to determine individual masses is a fit of the brighter component in the binary to theoretical models. Here the values in the catalog are model-dependent and usually come with large uncertainties. The crudest way to get the individual masses is to assume the mass of one component to have a typical value for this kind of object. Those cases are marked with a flag (SWD, SsdB, and SM2) of assumed values that are simply set by the authors. The most commonly assumed mass for WDs is 0.75 $M_\odot$ (e.g., Patterson et al. 2005),[9] and for sdB stars, it is in the range from 0.47 $M_\odot$ (e.g., Kupfer et al. 2015a) to 0.48–0.5 $M_\odot$ (e.g., Morales-Rueda et al. 2003). This results in an overdensity at those assumed masses in the full sample; see Figures 1 and 2.

2.4.2. Uncertainties and Inconsistencies

Where available, the estimated uncertainties are included in the catalog, and they replace the upper- and lower-limit columns in such cases. Figure 3 shows the uncertainties on the masses as error bars. Compared to Figure 1(a), it additionally contains the systems for which only a limit or range for a mass is available. The arrows indicate an upper or lower limit, while

[9] In recent years, a literary consensus has caused the canonical mass of a WD to decrease to 0.6 $M_\odot$, down from the 0.75 $M_\odot$ assumed in older papers. It should be noted that the mass of the other component will need to be changed accordingly if a different canonical mass is assumed.

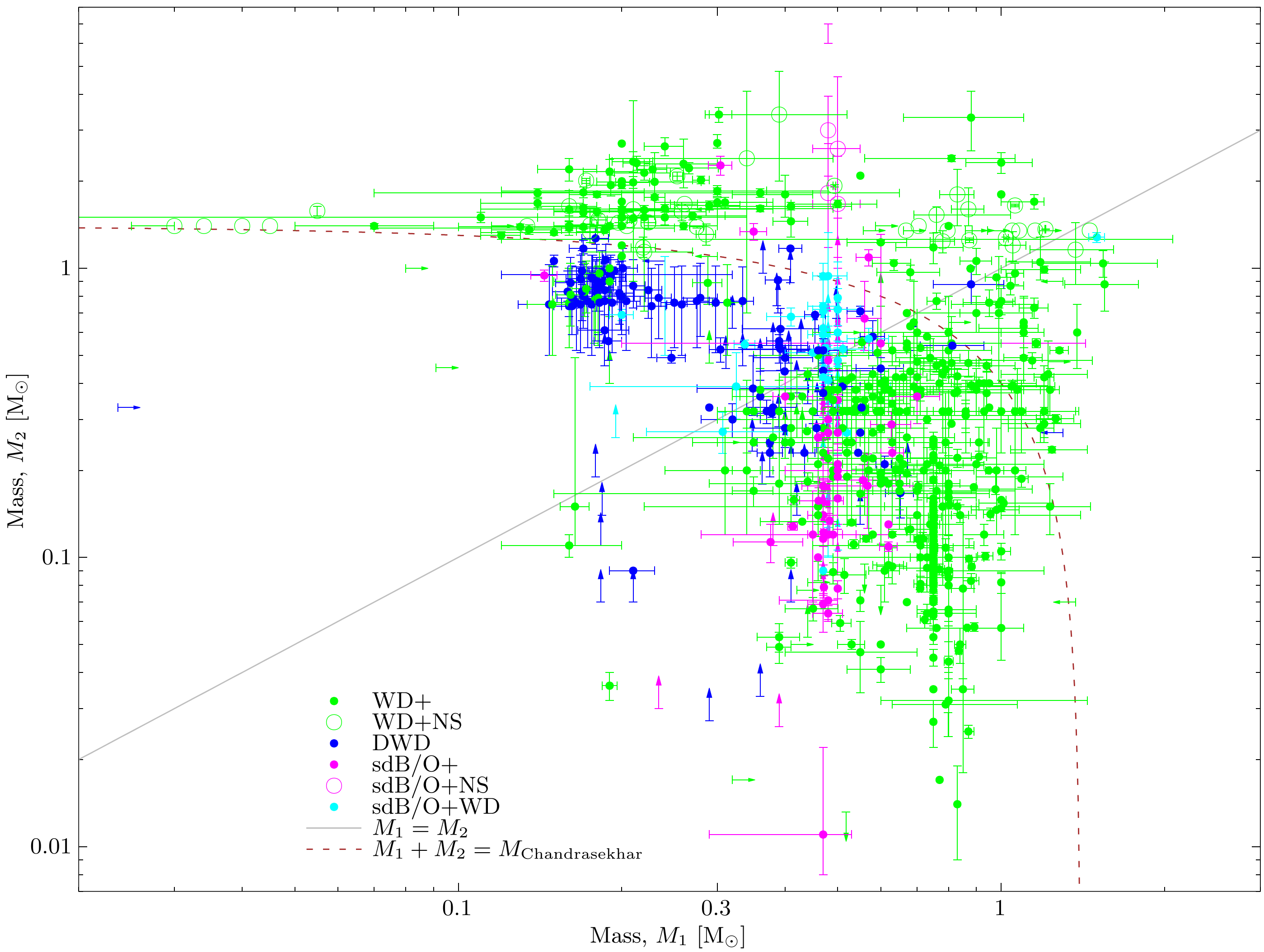

Figure 3. Mass–mass plot like in Figure 1(a). Additionally, it contains error bars. If there is no value, the error bars indicate the possible range, while an arrow is a limit (usually a lower limit). The colors show the type of the system, where NS companions are highlighted by open circles. The gray line separates the regions where the CE primary or secondary is more massive. The brown dashed line indicates a binary mass of 1.4 $M_\odot$.

the ranges represent systems where both limits are given. It should be noted that binaries with an assumed mass are usually displayed as sole data points without an uncertainty. At the same time, the figure gives an impression of how different the constraints from different observations are.

A few systems are included twice in the catalog (but not counted twice in Table 1 and only shown once in all plots), but the second occurrence is marked as a comment with a number sign at the beginning of the line and in the flag column. In those cases, it is unclear which reference provides the more reliable values when they are inconsistent between different authors. If a newer determination explains an inconsistency in older ones, usually the newer values are assumed to be reliable and used to replace the older ones.

2.4.3. Distances and Possible Detection Limits

From the cross-matching with the Gaia EDR3, we have obtained the distances, d, of most of the systems (see Figure 7 for the spatial distribution). Distances are calculated from the parallaxes given by Gaia by using the general zero-point offset of −0.017 mas (Lindegren et al. 2021). It should be noted that for some Gaia objects, the real offset could be up to −0.15 mas (Bailer-Jones et al. 2021). If the renormalized unit weight error of the systems is larger than or equal to 1.4 (Lindegren et al. 2021), the system is explicitly identified as having an uncertain parallax value in the catalog. Figure 4 shows the relations of the distances to some stellar parameters. There are eight systems with $d > 20$ kpc, which is probably due to large uncertainties in the Gaia parallaxes. Therefore, all of our systems are within 20 kpc, with the majority located within 1 kpc. In terms of mass, we do not find an obvious selection limit for the CE primary mass (panel (a)) or the more massive component mass (panel (d)); WDs as small as 0.15 $M_\odot$ and massive WDs close to the Chandrasekhar-mass limit (1.4 $M_\odot$) are included in our catalog. The sample of small WDs is mainly from one reference (Brown et al. 2016a). The massive companions are mostly neutron stars (see also Figure 3). However, we find a detection limit in terms of luminosity with no systems in the top left regions of panels (c) and (f). We emphasize, however, that only the large black dots are provided in the catalog. The rest of the dots are estimated from the radii and effective temperatures by making use of the Stefan–Boltzmann law.

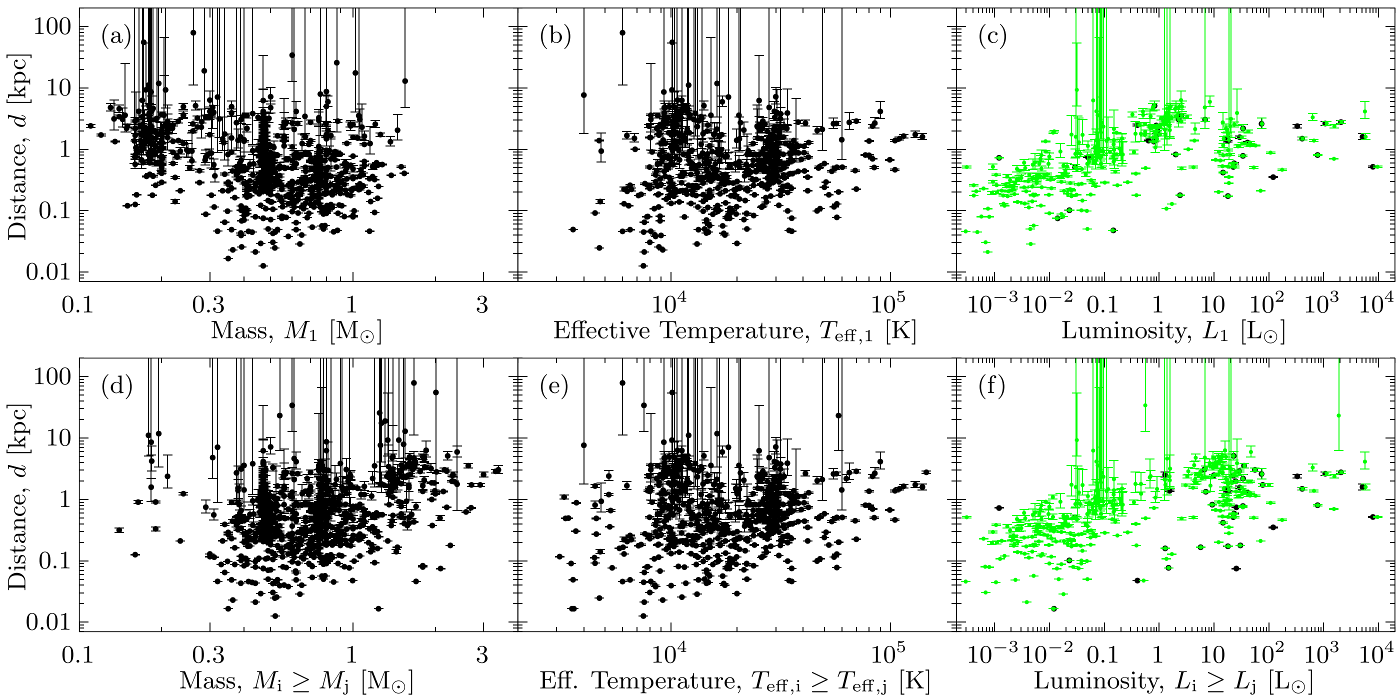

Figure 4. Distance depending on the mass, effective temperature, and luminosity. Panels (a)–(c): values of the CE primary component. Panels (d)–(f): values of the more massive, hotter, and more luminous star, respectively. The large black dots are the catalog values. The medium green dots are the luminosity calculated via the Stefan–Boltzmann law from the radius and effective temperature. The partially large uncertainties on the distances, especially for distant systems, are shown as error bars, while the error bars in the other quantities are not shown for clarity.

2.5. Comments on Outstanding Systems

Hen 2-428 (taken from Santander-García et al. 2015) stands out among DWD systems. Its mass ratio is measured to be very close to 1; hence, it contains two WDs with a similar mass. Additionally, their effective temperatures and radii are stated to be similar, too. Thus, both components may have formed in quick succession. This may indicate either a formation channel via stable mass transfer (Santander-García et al. 2015) or that the CE did not have a single donor, putting this system into a very distinct category of CEs. When both stars would overfill their Roche lobes at the same time, both would contribute to a CE and therefore eject both envelopes together. But this is not the only outstanding feature of Hen 2-428. Santander-García et al. (2015) derived radii of $0.68\,R_\odot$ for both WDs. With this radius, which is too large for a usual WD, the WDs would even fill their Roche lobes and should be in contact. A newer investigation by Reindl et al. (2020) of Hen 2-428 suggests lower WD masses.

Object PSR J1807–2500B (taken from Lynch et al. 2012) has by far the largest eccentricity in the catalog. It is a WD+NS binary located in the globular cluster NGC 6544. This very large eccentricity indicates that the binary orbit was probably changed significantly after the end of the CE. This could be related to the fact that the system is within a globular cluster and has had dynamical interactions with other stars within the cluster. Alternatively, the WD is not the last formed compact object in this binary. If the NS is the remnant of the donor of the CE, it might have received a large kick upon its formation, leading to the observed high eccentricity.

For system 0935+4411, the component masses are under debate. While Heller et al. (2009) found the WD to be the more massive star, Brown et al. (2016a) presented a WD mass of less than half of the companion's. Interestingly, the inferred effective temperature and surface gravity are similar in both references. This system has the largest inconsistency between two different references used for this catalog and therefore has two entries in the catalog; the second one is commented out. Additionally, this system has a very short orbital period while not currently observed to be undergoing mass transfer. It has a period more than an order of magnitude shorter than those of the usual CVs with such a massive hydrogen-rich star; see Figure 10(d). This might indicate that the companion is not an MS star; Heller et al. (2009) identified the companion as an M-type star. A number of systems are found a bit below the band of CVs in the WD+ sample (see Figure 10) that are candidates for having a hydrogen-depleted and unseen companion, e.g., another WD (in that case, they would be in the wrong subsample) or an NS (if massive enough).

Ultracompact X-ray binaries are thought to consist of an NS accreting material from a WD that has already lost most of its mass to the NS companion. Consequently, these systems are likely to have evolved significantly since the potential CE stage; see Section 3.1.1.

3. Discussion of the Evolution of the Binaries in the Catalog

This catalog is intended to facilitate the study of the CE phase by providing a sample of candidate post-CE systems. Additionally, it allows for the study of the future evolution of tight binaries as an initial population; see Appendix D.

3.1. The Origin of the Binaries

Consider, for example, the first category of binary in our catalog, WD+. These are binaries that consist of a WD orbiting a noncompact or unknown companion, generally an MS star. The orbital separations between the WD and its companion are too small to accommodate the giant progenitor of the WD, and this is the characteristic that makes these systems candidates for post-CE systems. The WD was once the core of its progenitor, usually a giant. The progenitor filled its Roche lobe. Possibly because it was more massive than its companion, dynamically stable mass transfer was not possible, and there was a CE instead. The orbital periods prior to the CE would have been on the order of months or years but are presently on the order of days or hours.

The second category we use to organize the catalog consists of DWDs. Again, those WDs are believed to be the remnant core of their progenitors. Most likely, both progenitors would have been at least massive enough to produce one of the present-day WDs. Because of binary interactions, the last formed WD could be more massive than its MS progenitor could have evolved into in single star evolution when it accreted enough material during the mass transfer leading to the formation of the first WD. It should be noted that the first formed WD is labeled as the secondary star in our catalog, while the CE primary is the last formed WD. If a DWD went through two CE phases, the intermediate system after the first WD formation would show up in the previously mentioned WD+ sample. Because we indicate the star according to the remnant of the last CE donor, the stars swap their roles between a first and second CE. The tightest DWD systems are the best candidates for binaries, which experienced two CEs.

The third category consists of an sdB/O star and its companion. An sdB/O star is usually a helium core–burning star that lost its hydrogen-rich envelope. Hence, those stars are more compact than normal MS stars but have a similar or even larger luminosity. When the companion is an unevolved star, it is clear that the sdB/O star is the remnant of a mass-transfer episode where its envelope got lost. In the other case of a WD companion, the sdB/O star is most likely the younger compact star because of the relatively short time of the core helium-burning phase compared to the cooling time of the WD.

3.1.1. Non-CE End States

The selection from observations is mainly determined by having a short period. But there is no guarantee that all of those systems went through a CE phase. There might be binaries that evolve into tight orbits even without the need of a CE evolution. This mainly applies to wider systems in the catalog and/or systems with massive companions.

If, for example, the donor is a subgiant filling its Roche lobe, its size may be small enough that the final orbital separation is on the order of $\sim 10\,R_{\odot}$. Depending on the uncertainties in the measurements of the masses and orbital period, such mass-transfer end states could be mistaken for CE end states. In such cases, the donor star would be Roche-lobe filling until the envelope collapses when its mass becomes negligibly small with respect to the core mass. The value of the donor's radius at the end of the mass transfer is not, however, uniquely determined. If it were, then it would be straightforward to know whether or not the condition of an end state of stable mass transfer is satisfied. Instead, we can determine whether it is satisfied for reasonable values of the radius that are consistent with what we know about stellar evolution and mass transfer.

The way we have explored the possibility that a given binary experienced stable mass transfer is to start with a set of stellar evolutionary models, conducted with the BEC code (Yoon et al. 2010), for single stars with zero-age MS (ZAMS) masses ranging from 0.5 to $100\,M_{\odot}$ at Milky Way metallicity, $Z = 0.0088$ (Brott et al. 2011; Kruckow et al. 2018). For each ZAMS mass,[10] we have interpolated the values of the core mass, envelope mass, and radius in intervals of $0.001\,M_{\odot}$ in core mass. In this simple model, the envelope mass is not necessarily close to the value of collapse, which introduces our primary source of uncertainty here. For example, the end state should correspond to the donor having lost most of its envelope; we therefore expect there to be some difference between the actual radius of the donor at the end of mass transfer and the radius we have employed.

For each post-CE candidate, we take the CE primary's mass and identify the state of each BEC star with this mass as its core mass. We therefore know the radius. We compare it with the radius of the Roche lobe associated with the core of the donor star in a circular orbit around its companion. If the stellar radius is smaller than the Roche lobe but comparable to it in size, then it is likely that stable mass transfer occurred. We add an additional condition. We consider only donor stars with mass $>0.7\,M_{\odot}$, so that they will have had a chance to evolve during the lifetime of the Galaxy. For most reasonable mass combinations of the two stars, this results in a period limit of a few to several days. Less than 10% of the systems in the catalog may be above this limit. It should be recalled that not passing this condition increases the likelihood that the system formed without involvement of a CE but does not exclude this possibility. Those systems, which had stable mass transfer instead of a CE formation, would tend to contribute to the high portion of the distribution of orbital separations/periods.

In binaries with more than one compact star, the assignment of the CE primary is not necessarily unique. Especially if the companion is a neutron star and the system shows a nonzero eccentricity, i.e., $e \gtrsim 0.2$, the last formed compact object might not be the WD. In those cases, it is unclear how much the system differs from the end state of a potential CE. The possibility of showing no signature of the end state cannot be excluded; thus, such systems have to be taken with additional caution.

For extremely low-mass WDs with a massive but compact companion, e.g., a neutron star, there might be other formation pathways beside a CE. If magnetic breaking and tides are strong enough, those systems may remain very tight during stable mass transfer (Chen et al. 2021).

Whenever we spot that any of the mentioned conditions (systems that may have avoided CE evolution) are met, we indicate this by a note in the data set.

3.1.2. Inner Binaries of Triples

A few of the binaries in the sample have a detected outer tertiary orbiting around the inner binary. Therefore, we indicate systems with a confirmed tertiary with a flag to indicate its triple nature (TRI). The fact that these systems exist in our catalog should come as no surprise. It is well known that about 10% of all stellar systems are triples in which the presence of the third star cannot be ignored (Raghavan et al. 2010; Michaely & Perets 2014; Moe & Di Stefano 2017), and 20% of all binaries, such as those hereby presented, are expected to have a tertiary at birth. Thus, the apparent paucity of such systems in our catalog might speak more to the observational biases inherent to the data that led to this catalog than an actual scarcity of triples in post-CE systems.

A mechanism known as Lidov–Kozai resonance (Kozai 1962; Naoz 2016) can drive the eccentricity of the inner binary into an oscillation with the inclination between the inner and outer orbits.

[10] We use only the models from 0.5 to 9 $M_{\odot}$ here.

The resulting decrease of the periastron coupled with other mechanisms, such as GWR (e.g., Thompson 2011) or tidal effects (e.g., Fabrycky & Tremaine 2007), may cause a permanent decrease of the inner orbital separation by a significant amount. Even without these other effects, an inner binary can be driven close enough to interact at periastron in ways that it would otherwise not, given the same initial semimajor axis. The timescale and therefore importance of this phenomenon depend on the distance and mass of the tertiary.

To date, there are many unknowns in the understanding of triple evolution; further discussion can be found in Appendix C. Even the effects of a CE phase in the inner binary on the outer orbit cannot be excluded. While a tertiary could have a long-term influence during the evolution, similar effects can act in a cluster environment by other stars which spend some time in the vicinity.

3.2. The Evolution between the End of a CE and the Observation

It is also possible that a binary that has emerged from a CE phase has had time to evolve before the present day. There is no definitive way to establish that the state we observe is different from the original post-CE state. Instead, we rely on general notions of probability.

Consider, for example, two WDs emerging from a CE. It is possible for the final orbital separation to be very small, small enough for the WDs to undergo a gravitational radiation–induced merger in a few thousand or million years. In such cases, however, the probability is low that we will detect the binary premerger, at least when compared with the probability that we will discover a system that lasts tens to thousands of times as long.

When the post-CE system consists of a WD and an extended star, similar considerations apply. In such systems, future evolution will involve an episode in which the extended star comes to fill its Roche lobe; see Sections 3.2.2 and 3.2.3. For the reasons given above, it is unlikely that we will discover the binary shortly before the extended star fills its Roche lobe. If, therefore, it is close to Roche-lobe filling, we judge that the binary is not likely to represent the unevolved end state of CE evolution.

3.2.1. Gravitational-wave Radiation

All binary or higher multiple star systems will lose orbital angular momentum through emission of GWR. In circular noninteracting binaries, such as post-CE binaries, this angular momentum loss will proceed on a timescale of (e.g., Peters 1964; Landau & Lifshitz 1975; Eggleton et al. 2006)

$$\tau_{\rm GR} = \frac{5}{32}\,\frac{c^5\,a^4}{G^3\,(M_1 + M_2)M_1\,M_2}. \quad (1)$$

This expression is called the gravitational merger timescale, with c the speed of light in a vacuum, G the gravitational constant, M_1 and M_2 the two involved masses, and a the semimajor axis of the system. We note—without going into detail, since most post-CE systems are expected to be circular or near-circular—that the gravitational-wave merger timescale depends on the eccentricity of the system. Accordingly, the semimajor axis of the system obeys

$$\frac{\dot{a}}{a} = -\frac{2}{\tau_{\rm GR}}. \quad (2)$$

As has been widely noted (e.g., Brown et al. 2016b; Pol et al. 2019), the dependence on the fourth power of the semimajor axis of the system prevents merging of wide binaries within the Hubble time unless some mechanism, such as mass transfer or CE evolution, is invoked to produce a closer binary. However, in post-CE systems, especially those involving more compact stars, such as He sdBs and WDs (Wang et al. 2013; Neunteufel et al. 2016; Neunteufel 2020), as opposed to hydrogen-rich MS stars, can be in such tight orbits that angular momentum loss due to GWR potentially results in the system being observed in a significantly closer configuration than at the conclusion of the most recent CE phase. Depending on the configuration of the system, the inferred lifetime of the most recently produced component may give some insight into the elapsed time since the most recent CE phase. In Figure 5(b), we show the cumulative distribution of the gravitational merger timescales of the systems contained in this catalog in relation to the Hubble time. We note that about $(36.6^{+2.1}_{-0.0})\%$ of the DWD systems can be expected to merge within the Hubble time, making these systems, if their total mass is (roughly) higher than the Chandrasekhar mass, putative SN progenitors (see, e.g., Pakmor et al. 2010; Ruiter 2020) or progenitors of R Coronae Borealis stars (for total binary masses significantly below the Chandrasekhar mass) in the double-degenerate merger channel (see, e.g., Webbink 1984; Zhang & Jeffery 2012). Figure 5(a) shows the total binary mass distribution of the systems in this catalog. We note that out of all sdB/O+ systems, about $(25.4^{+4.2}_{-4.2})\%$ of them will merge within the Hubble time. If $\tau_{\rm GR} > 10^9$ yr, which is the case for most of them, they likely also evolve into DWD systems. Where obtainable, we show the gravitational merger timescale, $\tau_{\rm GR}$, in relation to the cooling age, $t_{\rm cool}$, of the degenerate component in Figure 6(b). This is intended to give an indication of the time elapsed since the most recent CE phase. Additionally, this ratio can be transferred into a semimajor axis change if purely GWR influenced the orbit post-CE.

3.2.2. Mass Transfer

Post-CE orbits will be subject to subsequent modification if the system undergoes stable mass transfer when one of the component stars fills its Roche lobe. The material overfilling the star's Roche lobe will then be transferred to the accreting component, carrying with it a corresponding amount of orbital angular momentum. Generally, the semimajor axis of the system will react to mass transfer according to (see, e.g., Eggleton et al. 2006, chapter 3)

$$\frac{\dot{a}}{a} = 2\,\frac{\dot{M}_1}{M_1 + M_2}\,\frac{q^2 - 1}{q}, \quad (3)$$

assuming conservative mass transfer, which is expected for donor/accretor combinations (except WDs) of the stellar types contained in this catalog. If the mass transfer is not conservative, then angular momentum is lost from the system, causing a further decrease in orbital separation. Here $\dot{M}_1$ is the mass-loss rate from the donor star, and $q = \frac{M_1}{M_2}$ is the system's mass ratio. Accordingly, for cases of the less massive component transferring mass to the more massive one, the system's semimajor axis will

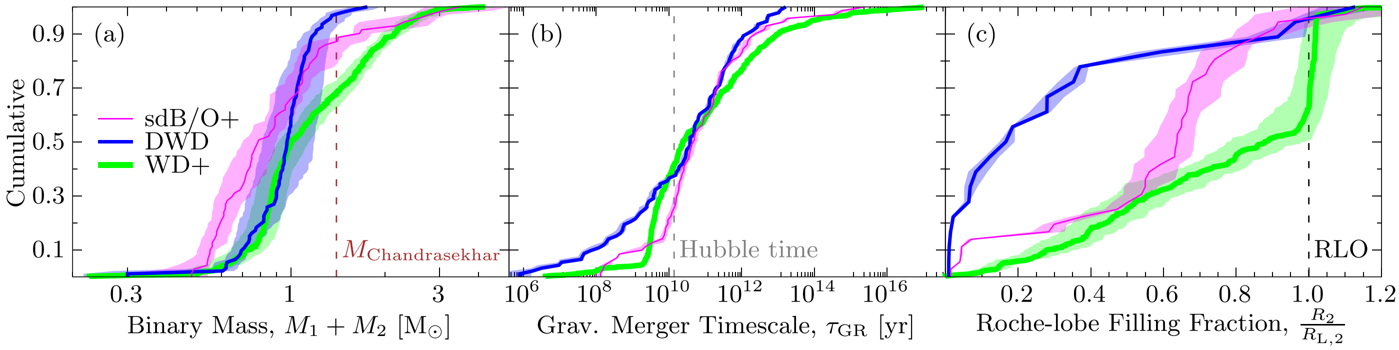

Figure 5. Cumulative distributions of calculated parameters. The color and line thickness indicate the binary type according to the key in panel (a). In panel (a), the binary mass, a mass of $M_{\rm Chandrasekhar} \approx 1.4\,M_\odot$, is marked by the dashed line. Panel (b) shows the timescale to merge the system by pure GWR (see Equation (1)), and 13.81 Gyr is marked by the dashed line. Panel (c) shows the fraction of the secondary radius and its Roche lobe; the equality of the two radii is marked, hence whether the companion undergoes Roche-lobe overflow (RLO). The required semimajor axis is always calculated via Kepler's third law and the Roche lobe with the fitting formula of Eggleton (1983). To show the uncertainty contours, the missing uncertainty values are assumed to be the geometric mean of the recorded ones. Additionally, we had to assume that the errors of the underlying quantities, e.g., the masses, are uncorrelated because of missing information on the correlation factors.

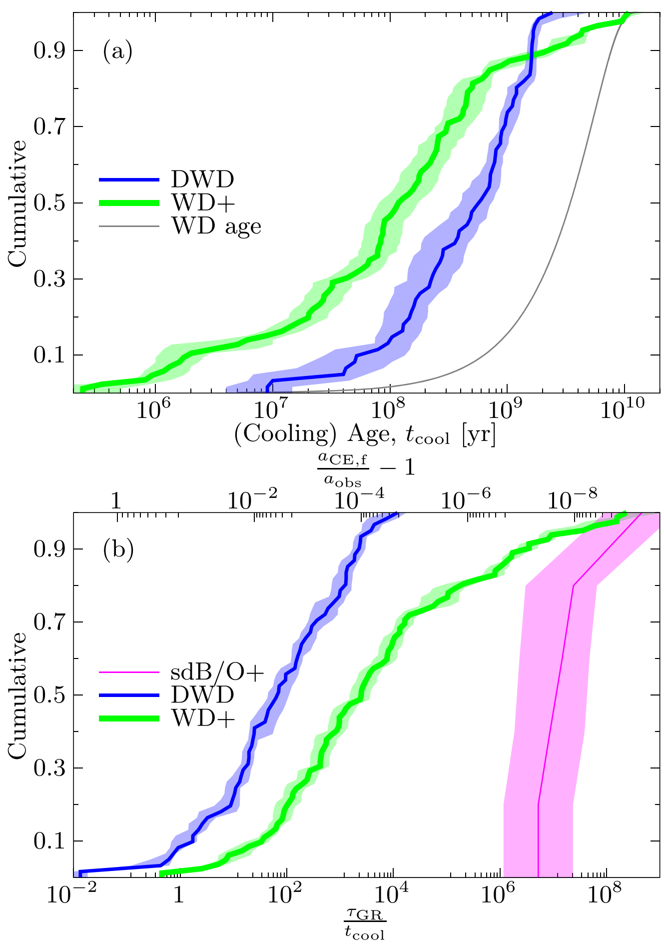

Figure 6. (a) Cumulative distribution of the (cooling) age of the catalog systems. The color and line thickness indicate the binary type. For comparison, the gray line shows the WD age distribution in the solar neighborhood (Kobayashi et al. 2020). (b) Cumulative distribution of the gravitational merger timescale, $\tau_{\rm GR}$, in units of the cooling age, $t_{\rm cool}$, of the catalog systems. The top axis shows the fractional change of the semimajor axis between the end of the CE, $a_{\rm CE,f}$, and the observation, $a_{\rm obs}$, if the orbital change is purely caused by GWR. The color and line thickness indicate the binary type. To show the uncertainty contours, missing uncertainty values are assumed to be the geometric mean of the recorded ones. Additionally, we had to assume that the errors of the underlying quantities, e.g., the masses, are uncorrelated because of missing information on the correlation factors.

increase, while in cases of the more massive component transferring mass to the less massive, the system's semimajor axis will decrease. Mass transfer due to Roche-lobe overflow (trivially) requires the mass-donating component to fill its Roche lobe. Stars overfilling their Roche lobes are correspondingly expected to exhibit higher mass-loss rates (Ritter 1988; Kolb & Ritter 1990). In Figure 5(c), we show the cumulative Roche-lobe filling fraction of the systems contained in this catalog. We emphasize the large jump for WD+ systems at unity, which is due to CVs being assigned to this class of binaries. Roche-lobe filling fractions exceeding unity by a significant margin may be caused by observational uncertainties. We expect this uncertainty to mainly arise from the radius determination and the fact that mass-transferring donors are nonspherical. This uncertainty becomes smaller for smaller Roche-lobe filling fractions.

Mass transfer has the potential to stabilize a binary system against decreasing orbital separation due to GWR depending on whether a critical mass-transfer rate $\dot{M}_{\rm crit}$ is exceeded. The condition for this effect can be written (Tutukov & Yungelson 1979; Neunteufel 2020)

$$\dot{M}_1 < \dot{M}_{\rm crit} = -\frac{32}{5}\frac{G^3}{c^5\,a^4}\frac{(M_1 + M_2)M_1^2\,M_2^2}{M_1 - M_2}. \tag{4}$$

Due to the dependence on a^{-4}, which places restrictions on the radius of the components via their Roche-lobe radius, this condition is usually fulfilled by default in most H-rich and evolved stars with extended envelopes, but not necessarily in interacting systems containing compact objects such as WDs or He sdBs, and has to be checked for independently. Most notably, interacting systems with a He sdB transferring material to a more massive WD may still exhibit decreasing orbital separations due to mass transfer being unable to overcome GWR emission.

In this catalog, systems known to currently undergo mass transfer are given the mass-transfer flag (MT). Systems containing a WD currently accreting H-rich material will be observationally distinguished as CVs and, hence, are designated by the CV flag in this catalog. However, we note that CVs (see Section 3.2.3) may, other than Roche-lobe overflow (RLOF)-induced mass transfer, be fueled by wind accretion.

Since none of the WDs in this catalog happen to be accreting He-rich material, and none of the nondegenerate stars happen to be accreting H-rich material, the MT is equivalent to a system with He-rich mass transfer onto a nondegenerate companion, while the CV flag is equivalent to a system transferring H-rich material onto a WD. Of the sample contained in the catalog, 25 systems are currently known to be undergoing mass transfer as defined in this section. We note that a number of sources in this catalog are observable as X-ray (NS accretors) and/or supersoft X-ray (WD accretors) sources.

3.2.3. Cataclysmic Variables

A WD in a compact binary with a H-rich MS star accreting H-rich material from a nondegenerate companion will undergo successive episodes of unstable hydrogen ignition at low mass-transfer rates, leading to the accreted material and burning products being ejected from the system. As the ejected material carries a certain amount of orbital angular momentum, this will affect the orbital evolution of the system. The frequency and magnitude of these eruptions depend on the accretion rate, with rates in the range 10^{-11}–$10^{-8}\,M_{\odot}\,\mathrm{yr}^{-1}$ commonly considered in the literature. Here higher accretion rates are connected to a higher outburst frequency and lower ejecta mass per individual outburst. (The CVs are extensively discussed in the literature; see, e.g., Robinson 1976; Spruit & Ritter 1983; Szkody et al. 2002; Ritter & Kolb 2003; Schmidt et al. 2005b; Hillman et al. 2020, and others).

Of our sample, 223 systems were observationally confirmed as CVs. Most of these can be found in catalogs of CVs (e.g., Ritter & Kolb 2003) as well. Due to uncertainties imposed by the orbital evolution in the post-CE phase, CVs should only be used as limiting cases.

3.2.4. Tidal Locking and Magnetic Braking

An extended star in a binary will be deformed by the gravitational field of its companion. This deformation and associated rotational shears will impact the rotation of the star, as well as, due to the quadrupole moment exerted by the tidal bulges, the orbital angular momentum of the system. Consequently, most post-CE systems will have only small eccentricities (see Figure 2(l)), and an extended companion will get tidally locked (see, e.g., Zahn & Bouchet 1989).

Magnetic braking acts through interaction of a star's magnetic field with its own wind, causing a star to spin down as angular momentum is exchanged between a rotating star and its wind, linearly moving outward. For binary stars, this loss of spin angular momentum affects the system's total orbital angular momentum via tidal interaction. Magnetic braking will cause a star to rotate slower than demanded by pure tidal effects, leading to a loss of total orbital angular momentum as tides cause the star to rotate faster. The efficiency of magnetic braking is currently a matter of debate (see, e.g., Marsh 2000; Eggleton et al. 2006; Fleming et al. 2019).

4. Summary

We have compiled a unified catalog of 839 post-CE candidates taken from the literature. The data set is probably incomplete in several different ways. First, the various observations of individual binaries and surveys all come with their own uncertainties and limitations. Second, there are systems missing in the catalog because they do not match the criterion of having derived masses, or some might not have been found in the literature search. Nevertheless, this catalog represents a unique resource toward unraveling the physics of the CE phase. Even prior to using its systems as inputs for calculations, we have been able to explore the relationships between the component masses and their orbital separation. Interesting patterns emerge in the figures shown in Section 2. These patterns surely provide clues to the physical processes producing these end states.

Individual post-CE candidates and small groups of them can provide reliable input for interesting studies. We anticipate that one of the most significant uses of this catalog will be to improve the parameterized methods currently used (such as the α and γ formalisms) that map the initial CE states to the CE end states. Another important use of the catalog is as a testing ground for hydrodynamic simulations that are currently taking on the challenge of computing CE evolution.

Observations of close binaries are ongoing, and the results are being published at an increasing rate. Thus, while this catalog is currently the best resource for the study of post-CEs, it will be useful to supplement its contents with new systems as they are discovered. There is, however, a crucial caveat: we have surveyed the vast literature on potential post-CEs and developed a set of uniform criteria for the selection of the candidates included here. While some post-CEs may have been missed, and some of the candidates we list may represent "false positives," the value of the careful selection of systems is that it provides a level of uniformity, important for subsequent uses of the catalog. Therefore, additions to the catalog should be made by employing similar selection criteria; see Section 2.1. This catalog and its future extensions will provide insight into the evolution of close binaries through the CE phase.

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This research has made use of the VizieR catalog access tool, CDS, Strasbourg, France (DOI: https://doi.org/10.26093/cds/vizier). The original description of the VizieR service was published in Ochsenbein et al. (2000). This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France (Wenger et al. 2000).

Data Availability

The catalog data set will be available in the online version. Additionally, the newest version of the data can be requested via email from mkruckow@ynao.ac.cn.

Appendix A
A Shorthand Catalog Version

Table 2 gives a summary description of the columns that are available in the catalog. The first six columns plus columns 50 and 59 are given in Table 3. If there is no value in columns 3 or 4, a lower or upper limit is taken from columns 7–10 accordingly.

Table 2
Content of the Columns in the Catalog

Column	Description
1	Names
2	Period in days
3 (7, 8)	Primary mass in $M_\odot$
4 (9, 10)	Secondary mass in $M_\odot$
5	Primary type
6	Secondary type
11 (12, 13)	Mass ratio = primary over secondary mass
14 (15, 16)	Semimajor axis in $R_\odot$
17 (18, 19)	Eccentricity
20 (21, 22)	Inclination in deg
23 (24, 25)	Primary radius in $R_\odot$
26 (27, 28)	Secondary radius in $R_\odot$
29 (30, 31)	Primary effective temperature in K
32 (33, 34)	Secondary effective temperature in K
35 (36, 37)	Primary luminosity in $L_\odot$
38 (39, 40)	Secondary luminosity in $L_\odot$
41 (42, 43)	$\log_{10}$ of the primary surface gravity in cm s^{-2}
44 (45, 46)	$\log_{10}$ of the secondary surface gravity in cm s^{-2}
47 (48, 49)	(Cooling) age in yr
50	Flags
51 and 52	R.A. and decl. in deg from Simbad[a]
53	Gaia EDR3 ID
54 and 55	R.A. and decl. in deg from Gaia EDR3[b]
56 (57, 58)	Distance estimate in kpc from Gaia EDR3[b] parallax
59/60	References
61	Notes

Notes. The column numbers in parentheses are the columns with the lower and upper limits. We refer to the CE primary as the donor of the possible CE and the secondary as its inspiraling companion. A list of the types and flags is given in Table 3 and explained in Sections 2.2 and 3.2.
[a] http://simbad.u-strasbg.fr/simbad/
[b] https://www.cosmos.esa.int/web/gaia/earlydr3

Table 3
Shorthand Version of the Catalog Showing the Name(s), Periods, Masses (Sometimes Only Limits), and Types of the Two Stars, a Flag to Indicate Possible Issues, and the Reference(s)

Name(s)	Period (days)	$Mass_1$ ($M_\odot$)	$Mass_2$ ($M_\odot$)	$Type_1$	$Type_2$	Flag(s)	Reference(s)
RX J0806.3+1527/HM Cnc	0.0037214020	0.55	0.27	WD	WD	MT	330, 407, 343
ZTF J1539+5027	0.004800828014	0.610	0.210	WD	WD	–	15
ZTF J2243+5242	0.00611035664	0.349	0.384	WD	WD	–	16
V407 Vul/RX J1914.4+2456	0.00659022	0.8	0.177	WD	–	MT/S	330, 200
ES Cet	0.007178376	0.8	0.161	WD	–	MT/S	99, 200
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

Notes. The full catalog is available in the online version in machine-readable format. It contains additional columns about the mass ranges, mass ratio, separation, eccentricity, inclination, radii, effective temperatures, luminosities, surface gravity, and age estimate, if available. Types: WD, white dwarf; sdB/sdO, subdwarf B/O star; BD, brown dwarf; MS, main-sequence star; NS, neutron star; BH, black hole; BS, blue straggler; and dash, unclassified, otherwise spectral type. Flags: S, statistically inferred mass (most likely inclination); MT, mass transfer; CV, cataclysmic variable; TRI, triple; SsdB, assumed sdB mass; Sq, assumed mass ratio; SM2, assumed companion mass; SWD, assumed WD mass; and dash, best reliable candidates.

References. (1) Almenara et al. (2012); (2) Arnold et al. (1976); (3) Arenas et al. (2000); (4) Almeida et al. (2017); (5) Antoniadis et al. (2013); (6) Aungwerojwit et al. (2007); (7) Afsar & Ibanoğlu (2008); (8) Araujo-Betancor et al. (2003); (9) Antoniadis et al. (2016); (10) Armstrong et al. (2012); (11) Antoniadis et al. (2012); (12) Borges & Baptista (2005); (13) Baptista et al. (2003); (14) Bhat et al. (2008); (15) Burdge et al. (2019a); (16) Burdge et al. (2020a); (17) Baptista et al. (1998); (18) Barlow et al. (2011); (19) Beuermann et al. (2013); (20) Burdge et al. (2019b); (21) Breedt et al. (2012a); (22) Brown et al. (2016a); (23) Breedt et al. (2012b); (24) Beuermann et al. (2004); (25) Bianchini (1980); (26) Bai et al. (2016); (27) Brown et al. (2010); (28) Brown et al. (2012); (29) Brown et al. (2013); (30) Brown et al. (2011a); (31) Barlow et al. (2013); (32) Brown et al. (2011b); (33) Brown et al. (2017); (34) Bloemen et al. (2012); (35) Bours et al. (2015); (36) Bloemen et al. (2011); (37) Bours et al. (2014); (38) Burdge et al. (2020b); (39) Bell et al. (1994); (40) Beuermann & Reinsch (2008); (41) Bitner et al. (2007); (42) Burwitz et al. (1999); (43) Burwitz et al. (1998); (44) Bruch (2003); (45) Breton et al. (2012); (46) Baptista et al. (1994); (47) Breedt et al. (2017); (48) Beuermann et al. (1992); (49) Beuermann & Thomas (1990); (50) Baran et al. (2019); (51) Bruch et al. (2001); (52) Bassa et al. (2003); (53) Bassa et al. (2006a); (54) Bassa et al. (2006b); (55) Badenes et al. (2013); (56) Bergeron et al. (1994); (57) Bleach et al. (2000); (58) Bergeron et al. (1989); (59) Coughlin et al. (2020); (60) Casewell et al. (2020); (61) Corcoran et al. (2021a); (62) Casewell et al. (2012); (63) Crampton & Cowley (1977); (64) Cameron et al. (2020); (65) Cui et al. (2020);(66) Callanan et al. (1998); (67) Corcoran et al. (2021b); (68) Camilo et al. (2001); (69) Copperwheat et al. (2010);

(70) Copperwheat et al. (2011b); (71) Copperwheat et al. (2011a); (72) Chen et al. (1995); (73) Carter et al. (2011); (74) Danziger et al. (1993); (75) de Martino et al. (2006); (76) Desvignes et al. (2016); (77) Drake et al. (2014); (78) Drake et al. (2009); (79) Delfosse et al. (1999); (80) Drechsel et al. (2001); (81) De Marco et al. (2008); (82) Debes et al. (2015); (83) Dhillon et al. (1991); (84) Derekas et al. (2015); (85) Dai & Qian (2010); (86) Diaz & Ribeiro (2003); (87) Dai et al. (2017); (88) Deller et al. (2016); (89) Dunford et al. (2012); (90) Edelmann et al. (2006); (91) Edwards & Bailes (2001); (92) Esmer et al. (2021); (93) Echevarría et al. (2007a); (94) Edelmann (2008); (95) Echevarría et al. (2019); (96) Edelmann et al. (2005); (97) Edelmann et al. (2004); (98) Echevarría et al. (2007b); (99) Espaillat et al. (2005); (100) El-Badry et al. (2021); (101) Echevarría et al. (2016); (102) Echevarría et al. (2008); (103) Fontaine et al. (2011); (104) Farihi et al. (2008); (105) Fonseca et al. (2021); (106) Feline et al. (2004b); (107) Feline et al. (2004a); (108) For et al. (2008); (109) For et al. (2010); (110) Faigler et al. (2015); (111) Ferguson et al. (1999); (112) Friend et al. (1990a); (113) Friend et al. (1990b); (114) Fonseca et al. (2016); (115) Ferdman et al. (2010); (116) Gänsicke et al. (2004); (117) Geier et al. (2012); (118) Gianninas et al. (2014); (119) Gies et al. (2008); (120) Geier et al. (2009); (121) Green et al. (2004); (122) Green et al. (2005); (123) Guo et al. (2017); (124) Geier et al. (2013a); (125) Geier et al. (2010a); (126) Green et al. (2018a); (127) Geier et al. (2010b); (128) Gizis (1998); (129) Geier et al. (2008); (130) Gänsicke et al. (2006); (131) Geier et al. (2011b); (132) Green et al. (2018b); (133) Geier et al. (2013b); (134) Geier et al. (2007); (135) Geier et al. (2011a); (136) Geier et al. (2014); (137) Godon & Sion (2021); (138) Güver et al. (2010);(139) Guo et al. (2015); (140) Hillwig et al. (2010); (141) Hermes et al. (2014); (142) Hutchings et al. (1985); (143) Hogg et al. (2020); (144) Heber et al. (2004); (145) Hellier (1997); (146) Hessman (1988); (147) Hillwig et al. (2015); (148) Hillwig et al. (2017); (149) Hermes et al. (2015); (150) Howell et al. (2006); (151) Heller et al. (2009); (152) Hilditch et al. (1996); (153) Hillwig et al. (2016); (154) Hermes et al. (2012); (155) Hong et al. (2017); (156) Hoard et al. (2004); (157) Hallakoun et al. (2016); (158) Hermes et al. (2013); (159) Haswell et al. (1997); (160) Hamilton & Sion (2004); (161) Howell et al. (1993); (162) Hawkins et al. (1990); (163) Hernandez et al. (2021); (164) Holberg et al. (1995); (165) Horne et al. (1986); (166) Horne et al. (1991); (167) Horne et al. (1993); (168) Hernandez et al. (2017); (169) İbanoğlu et al. (2005); (170) Jones et al. (2014); (171) Jacoby et al. (2007); (172) Jones et al. (2015); (173) Jones et al. (2019); (174) Jones & Lyne (1988); (175) Jeffery & Simon (1997);(176) Kruse & Agol (2014); (177) Kilic et al. (2010a); (178) Kasian (2012); (179) Kuerster & Barwig (1988); (180) Kilic et al. (2007); (181) Kilic et al. (2009); (182) Kilic et al. (2010b); (183) Kilic et al. (2011a); (184) Kilic et al. (2012); (185) Kupfer et al. (2020a); (186) Kilic et al. (2021); (187) Kaplan et al. (2014b); (188) Kilic et al. (2017); (189) Kilic et al. (2011b); (190) Kilic et al. (2011c); (191) Kupfer et al. (2020b); (192) Kupfer et al. (2015b); (193) Kupfer et al. (2015a); (194) Kupfer et al. (2014); (195) Kilic et al. (2014); (196) Karl et al. (2006); (197) Kilkenny (2011); (198) Kosakowski et al. (2021); (199) Koen et al. (2010); (200) Kupfer et al. (2018); (201) Kirichenko et al. (2020); (202) Kaplan et al. (2014c); (203) Karl et al. (2003); (204) Kawka et al. (2012); (205) Klepp & Rauch (2011); (206) Kaluzny et al. (2007); (207) Krzeminski (1962); (208) Kudritzki & Simon (1978); (209) Kupfer et al. (2016); (210) Kilkenny et al. (1988); (211) Kato et al. (2021); (212) Kaspi et al. (1994); (213) Kawka et al. (2008); (214) Kawka et al. (2002); (215) Kaplan et al. (2014a); (216) Kawka et al. (2015); (217) Kára et al. (2021); (218) Landsman et al. (1997); (219) Lanning (1982); (220) Littlefair et al. (2014b); (221) Littlefair et al. (2014a); (222) Littlefair et al. (2006b); (223) Littlefair et al. (2007); (224) Littlefair et al. (2008); (225) Littlefair et al. (2006a); (226) Lynch et al. (2012); (227) Linnell et al. (2009); (228) Lisker et al. (2005); (229) Levitan et al. (2014); (230) Lee et al. (2009); (231) Law et al. (2012); (232) Lanning & Pesch (1981); (233) Landsman et al. (1993); (234) Mennickent & Arenas (1998); (235) Maxted et al. (2011); (236) Marsh (2000); (237) Marsh (1995); (238) Maxted et al. (2014b); (239) Maxted et al. (2002a); (240) Mennickent & Diaz (1996); (241) Marsh et al. (1995); (242) McKee et al. (2020); (243) Marsh et al. (2016); (244) Marsh et al. (2011); (245) Maxted et al. (2001); (246) Manchester et al. (2005); (247) McAllister et al. (2015); (248) McAllister et al. (2017a); (249) McAllister et al. (2017b); (250) McAllister et al. (2019); (251) Maxted & Marsh (1999); (252) Moran et al. (1997); (253) Martínez-Pais et al. (2000); (254) Maxted et al. (2002b); (255) Maxted et al. (2000a); (256) Maxted et al. (2002c); (257) Morales-Rueda et al. (2003); (258) Maxted et al. (2004); (259) Morales-Rueda et al. (2005); (260) Maxted et al. (1998); (261) Moran et al. (1999); (262) Maxted et al. (2000c); (263) Maxted et al. (2000b); (264) Mendez & Niemela (1981); (265) Maxted et al. (2006); (266) Maxted et al. (2007); (267) Mennickent & Sterken (1998); (268) Mason et al. (2001); (269) Maxted et al. (2013); (270) Maxted et al. (2014a); (271) Morales-Rueda et al. (2002); (272) Mereghetti et al. (2010); (273) Mumford (1969); (274) Muirhead et al. (2013); (275) Marino & Walker (1974); (276) Miszalski et al. (2016); (277) Mason et al. (2019); (278) Napiwotzki et al. (2001); (279) Nebot Gómez-Morán et al. (2011); (280) Napiwotzki et al. (2004); (281) Napiwotzki et al. (2020); (282) Napiwotzki et al. (2002); (283) Napiwotzki et al. (2007); (284) Nelemans et al. (2005); (285) Neustroev et al. (2011); (286) Nice et al. (2008); (287) Nice et al. (2003); (288) Neustroev & Zharikov (2008); (289) O'Brien et al. (2001); (290) Østensen et al. (2010); (291) Østensen et al. (2013); (292) O'Donoghue et al. (2003); (293) O'Toole et al. (2006); (294) Orosz et al. (2001); (295) Østensen et al. (2014); (296) Orosz & Wade (1999); (297) Orosz et al. (1999); (298) Pollacco & Bell (1994); (299) Pandel et al. (2002); (300) Penning (1985); (301) Patterson et al. (2002); (302) Pyrzas et al. (2012); (303) Pyrzas et al. (2009); (304) Parsons et al. (2013); (305) Parsons et al. (2021); (306) Parsons et al. (2017); (307) Pavlenko et al. (2021); (308) Pablo et al. (2011); (309) Patterson et al. (2005); (310) Pallanca et al. (2013); (311) Prodan & Murray (2015); (312) Parsons et al. (2010a); (313) Parsons et al. (2010b); (314) Parsons et al. (2012a); (315) Parsons et al. (2012b); (316) Polubek et al. (2007); (317) Parsons et al. (2015); (318) Pala et al. (2018); (319) Peters & Thorstensen (2006); (320) Pietrzyński et al. (2012); (321) Provencal et al. (1997); (322) Qian et al. (2007); (323) Qian et al. (2009); (324) Ribeiro & Baptista (2011); (325) Roelofs et al. (2007a); (326) Reimers et al. (1988); (327) Roelofs et al. (2005); (328) Roelofs et al. (2007b); (329) Rebassa-Mansergas et al. (2008); (330) Ramsay et al. (2002); (331) Reardon et al. (2016); (332) Rolfe et al. (2000); (333) Ritter & Kolb (2003); (334) Rodríguez-Gil & Martínez-Pais (2002); (335) Rodríguez-Gil et al. (2001); (336) Rosen et al. (1987); (337) Rebassa-Mansergas et al. (2021); (338) Rappaport et al. (2015); (339) Rebassa-Mansergas et al. (2014); (340) Rebassa-Mansergas et al. (2017); (341) Rappaport et al. (2009); (342) Ruiz et al. (2001); (343) Roelofs et al. (2010); (344) Ransom et al. (2014); (345) Rodríguez-Gil et al. (2015); (346) Rodríguez-Gil et al. (2020); (347) Rodríguez-Gil et al. (2009); (348) Reed et al. (2010); (349) Ratti et al. (2013a); (350) Ratti et al. (2013b); (351) Rebassa-Mansergas et al. (2012); (352) Shimansky et al. (2013); (353) Steele et al. (2011); (354) Schaffenroth et al. (2015);(355) Saffer et al. (1994); (356) Shimansky et al. (2012); (357) Shimansky et al. (2015); (358) Shimansky et al. (2002); (359) Shimansky et al. (2003); (360) Shimanskii et al. (2004); (361) Smak et al. (2001); (362) Spogli & Claudi (1994); (363) Schaefer (2020); (364) Schaffenroth et al. (2021); (365) Sahman et al. (2013); (366) Smith et al. (1998); (367) Simon et al. (1985); (368) Schaffenroth et al. (2014a); (369) Schaffenroth et al. (2013); (370) Sing et al. (2007); (371) Schaffenroth et al. (2014b); (372) Schreiber et al. (2008); (373) Scaringi et al. (2013); (374) Shafter & Holland (2003); (375) Shafter & Hessman (1988); (376) Shafter (1983); (377) Sing et al. (2004); (378) Smith et al. (2006); (379) Shimanskii (2002); (380) Steeghs et al. (2007); (381) Stroeer et al. (2007); (382) Schwope et al. (2011); (383) Szkody & Ingram (1994); (384) Şener & Jeffery (2014); (385) Skillman et al. (2002); (386) Savoury et al. (2011); (387) Schindewolf et al. (2015); (388) Saffer et al. (1988); (389) Salazar et al. (2017); (390) Schwope & Mengel (1997);(391) Silvotti et al. (2012); (392) Shimansky et al. (2008); (393) Shimansky et al. (2009); (394) Skillman et al. (1999); (395) Steeghs et al. (2003); (396) Stella et al. (1987); (397) Santander-García et al. (2015); (398) Steele et al. (2013); (399) Sion et al. (2001); (400) Schmidt et al. (2007); (401) Silvotti et al. (2020); (402) Staude et al. (2001); (403) Schmidt et al. (2005a); (404) Stauffer (1987); (405) Schwope et al. (1993); (406) Stefanov (2021); (407) Strohmayer (2005); (408) Schoembs & Vogt (1981); (409) Shahbaz & Wood (1996); (410) Saffer et al. (1993); (411) Shimanskii et al. (2012); (412) Subebekova et al. (2020); (413) Thorsett et al. (1993); (414) Telting et al. (2014); (415) Thoroughgood et al. (2001); (416) Thoroughgood et al. (2005); (417) Thoroughgood et al. (2004); (418) Thorstensen et al. (2004); (419) Tappert et al. (2007); (420) Tappert et al. (2009); (421) Tovmassian et al. (2004); (422) Telting et al. (2012); (423) Tokovinin (1997); (424) Tovmassian et al. (2014); (425) Tovmassian et al. (1999); (426) Tappert et al. (2013); (427)Tappert et al. (1997); (428) Tovmassian et al. (2010); (429) Uthas et al. (2010); (430) Vučković et al. (2007); (431) van Straten et al. (2001); (432) van Kerkwijk et al. (2000); (433) van Kerkwijk et al. (1996); (434) Van Grootel et al. (2008); (435) Van Grootel et al. (2014); (436) van den Besselaar et al. (2007); (437) van Roestel et al. (2021); (438) Vennes et al. (2012); (439) van Roestel et al. (2018); (440) Vogt (1981); (441) van Kerkwijk et al. (2010); (442) Vanderburg et al. (2020); (443) Vande Putte et al. (2003); (444) van Spaandonk et al. (2010); (445) Vennes et al. (2011); (446) Vennes et al. (1999); (447) Vaccaro & Wilson (2003); (448) Vaccaro et al. (2015); (449) Wang & Chakrabarty (2004); (450) Wood et al. (2002); (451) Watson et al. (2003); (452) Welsh et al. (2007); (453) Wade & Horne (1988); (454) Wood et al. (1989); (455) Wu et al. (2002); (456) Wang et al. (2018); (457) Wood & Saffer (1999); (458) Watson et al. (2007); (459) Warner & Thackeray (1975); (460) Wevers et al. (2016); (461) Wakamatsu et al. (2021); (462) Wolff et al. (1999); (463) Zhang et al. (2016); (464) Zhang et al. (2017); (465) Zhu et al. (2011); (466) Zhu et al. (2015); (467) Zorotovic et al. (2011); (468) Zorotovic et al. (2016).

(This table is available in its entirety in machine-readable form.)

Appendix B
Additional Figures

The collection from many different observational campaigns results in good sky coverage; see Figure 7.

Figures 8–10 again show the basic parameters but for the three main classes of systems separately.

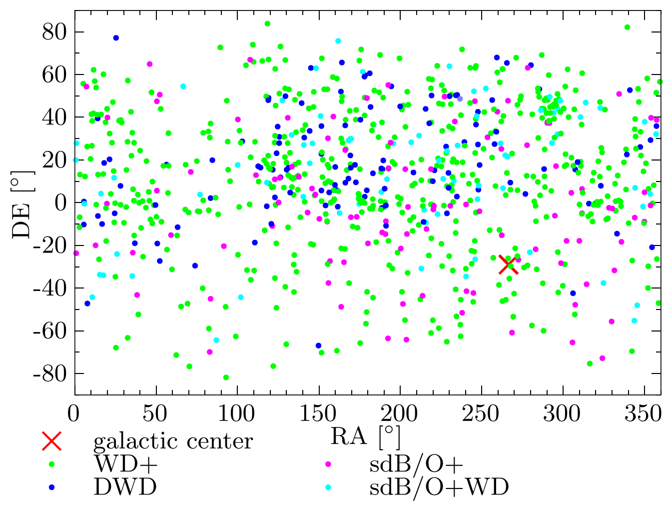

Figure 7. Positions of the catalog members in J2000 coordinates. The type of the system is color coded. The red cross marks the position of the galactic center.

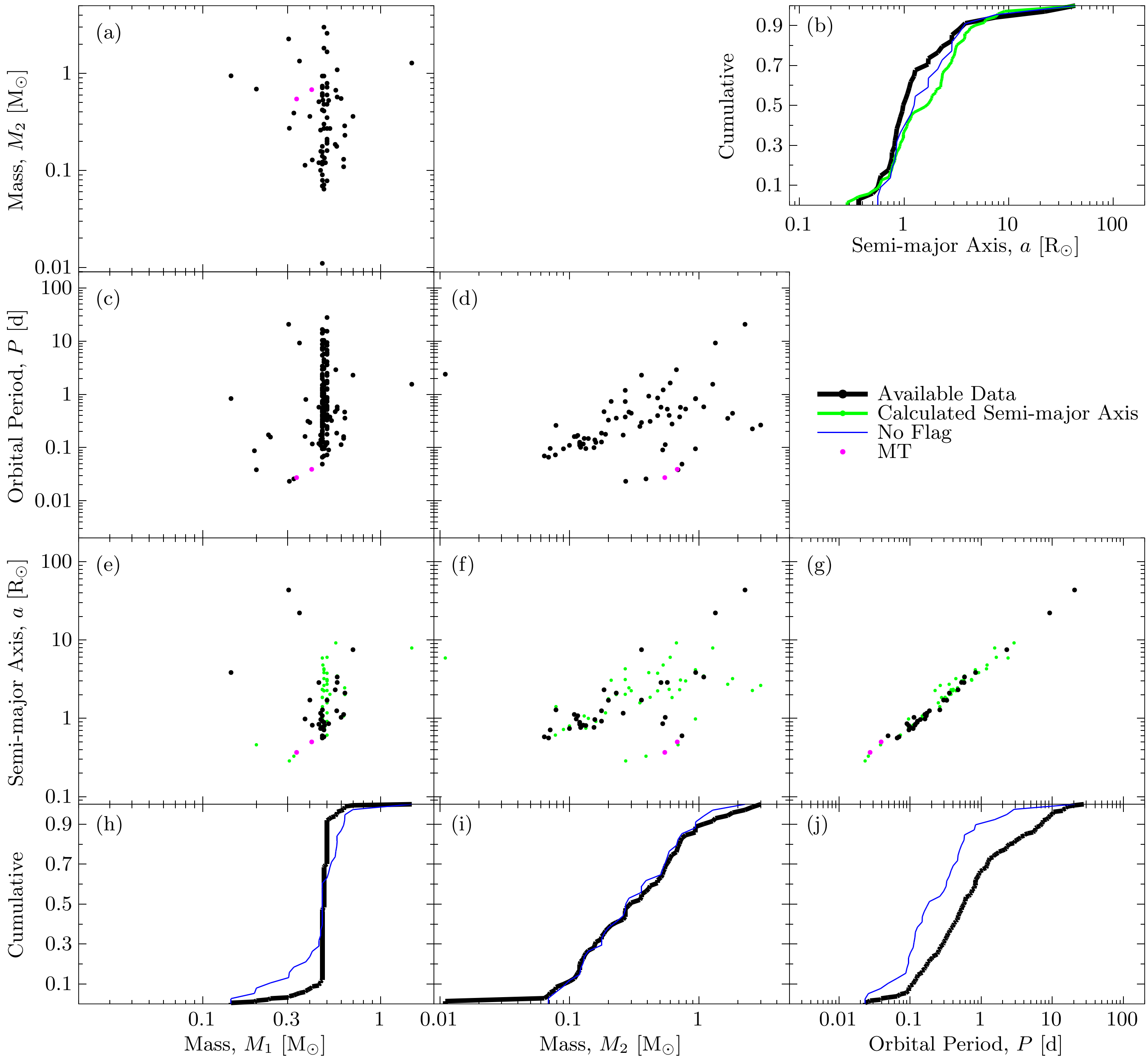

Figure 8. Similar to Figure 1 but showing only systems with an sdB/O star; see second column in Table 1. Additionally, the mass-transferring systems are marked in purple.

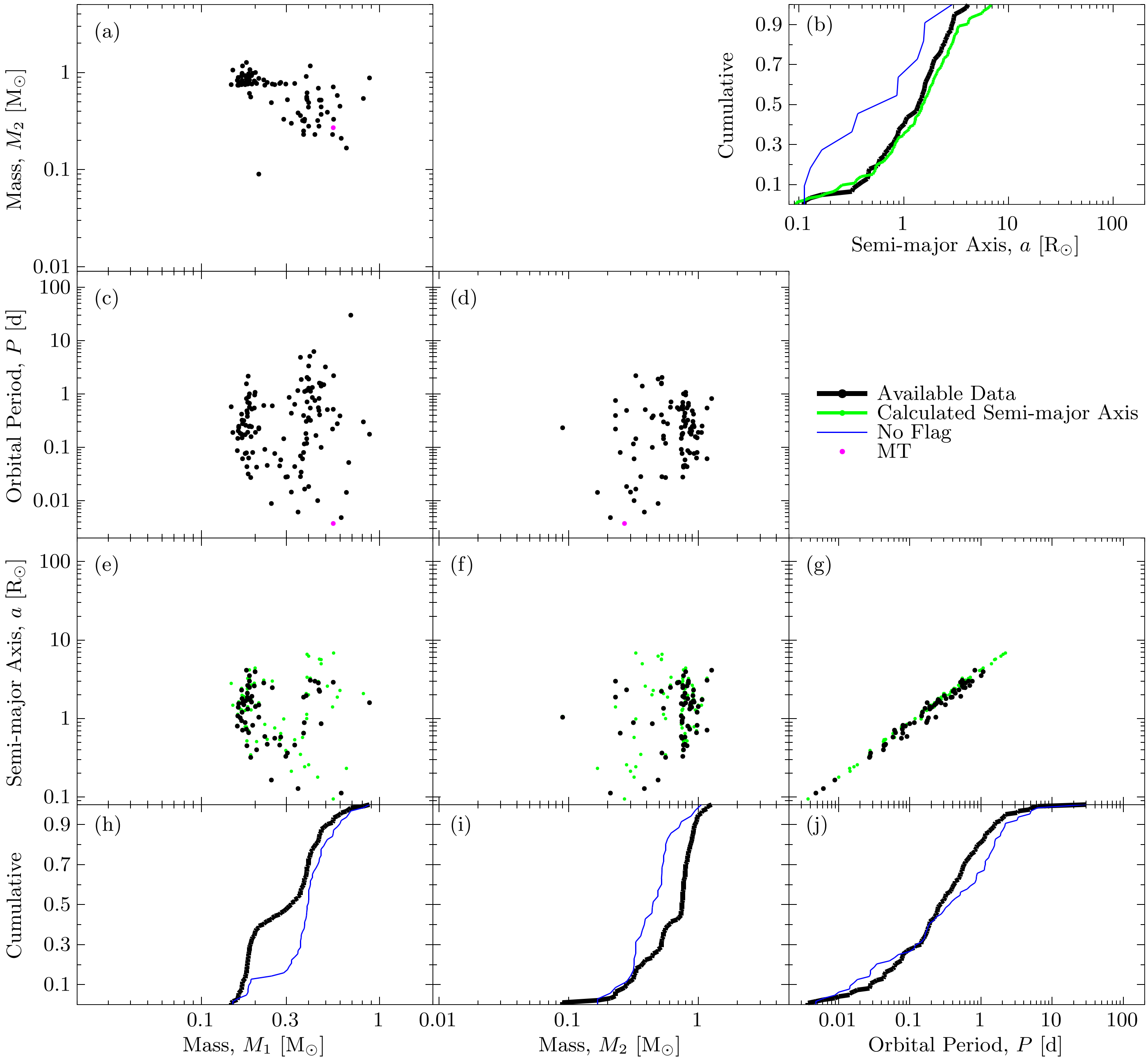

Figure 9. Similar to Figure 1 but showing only DWD systems; see third column in Table 1. Additionally, the mass-transferring systems are marked in purple.

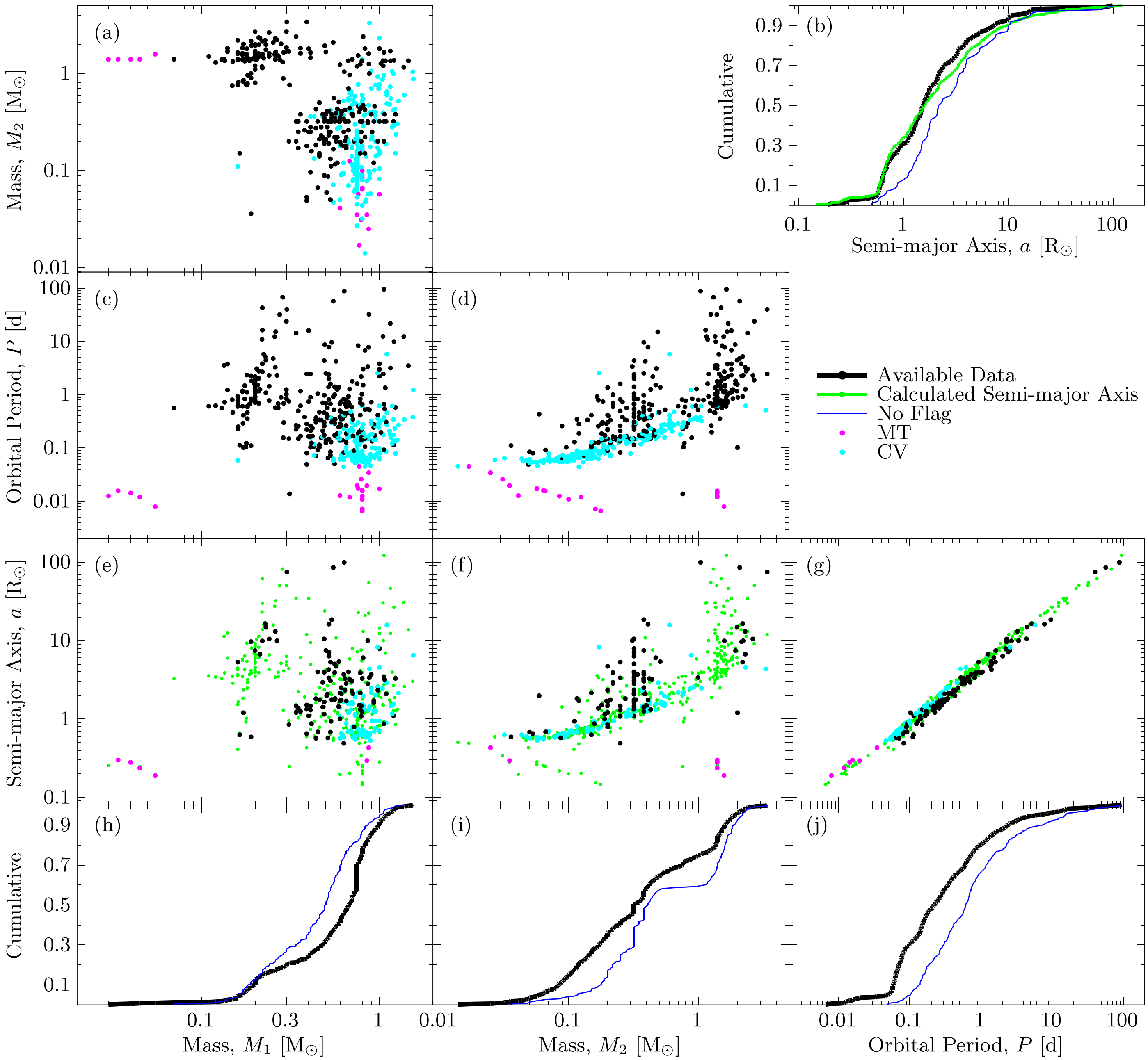

Figure 10. Similar to Figure 1 but showing only WD systems with non-WD companions; see fourth column in Table 1. Additionally, the mass-transferring systems are marked in purple, and the systems showing observational features of CVs are marked in teal.

Appendix C
Very Close Triples

Lidov–Kozai resonance requires an inclination between the inner and outer orbital plane. To date, this is perhaps the most thoroughly studied effect a tertiary can have.

For closer tertiaries, which are almost but not quite close enough to exchange matter with the inner binary, tertiary tidal effects can drive the inner binary into tighter orbits (Fuller et al. 2013; Gao et al. 2018, 2020). Even closer tertiaries can directly undergo RLOF, resulting in an even greater impact on the inner binary (Di Stefano 2019, 2020). For those tertiaries that lie yet even closer to their companion inner binaries, they themselves may be responsible for the CE, although whether or not the subsequent system can survive as a triple is questionable, according to recent studies (Comerford & Izzard 2020; Glanz & Perets 2021). However, as these processes were only recently brought to the attention of the astrophysical community, frantic efforts to make sense of them are still underway, and one should exercise caution when estimating the magnitude of their influence.

Appendix D
SN Progenitor Scenarios Applicable to the Systems in This Catalog

Some of the tighter systems contained in this catalog are likely to interact again within a Hubble time, which will, depending on the current structure of the system, lead to the formation of either stellar remnants of different sorts or transient events. This section is intended to provide a brief overview of the most important transients and remnants to be expected, though we encourage the user of this catalog to analyze individual systems with regard to their most likely outcome.

Any conceivable SN mechanism applicable to the systems contained in this catalog, due to none of the companions lying in a mass range subject to any SN mechanism accessible to single stars, must involve mass transfer or violent mergers of the companion stars. This results in either a thermonuclear SN or (in ONeMg WDs) electron capture and collapse into an NS (accretion-induced collapse). Progenitor scenarios for thermonuclear SNe are usually grouped, depending on the terminal state of the system, into single-degenerate (see, e.g., the classical paper by Whelan & Iben 1973, and newer sources below) and double-degenerate (see, e.g., classical papers by Iben & Tutukov 1984 and Webbink 1984, and newer sources below) channels, the former denoting involvement of one WD and one nondegenerate star and the latter suggesting involvement of two WDs. In the literature, total system masses both exceeding and falling short of the Chandrasekhar mass have been proposed as possible Type Ia SN (and related) progenitors (see, e.g., Nomoto 1982a, 1982b; Tutukov & Yungelson 1994). We refrain from making any predictions about the eventual outcome of our systems but instead give a short summary of possible progenitor channels.

Single-degenerate hydrogen donor. In this scenario, the donor star is assumed to be either a hydrogen-rich MS star or an evolved star with a hydrogen-rich envelope. This star then donates material to its companion WD. Unstable ignition of the accumulated material is associated with CV evolution. The hydrogen may also be processed through stable burning into helium, which may then ignite, triggering a secondary detonation in the WD's CO core (this is known as the double-detonation scenario), or, when the WD approaches the Chandrasekhar mass, a detonation is triggered in the WD's center as the degenerate electron gas becomes unstable against further gravitational collapse (i.e., the classic mechanism according to Chandrasekhar; see, e.g., Hillebrandt & Niemeyer 2000; Ruiter 2020, the latter being a recent review).

Single-degenerate helium donor. Alternatively, the nondegenerate component is a hydrogen-depleted star. The physical radii of these stars are about 1 order of magnitude smaller than those of hydrogen-rich stars of the same mass. In this case, the system is required to be much closer than in the hydrogen donor case, which is conducive to the argument that most SN progenitors of this type are necessarily post-CE systems. At high mass-transfer rates, the helium will either be processed stably into carbon and oxygen or undergo a sequence of unstable helium ignitions, resulting in successively more and more massive He novae, which may, if sufficient CO can be built up, result in a Chandrasekhar-like detonation. At low rates, the helium may be accumulated quiescently, building up until it ignites explosively, which may then trigger a secondary explosion of the CO core (Nomoto 1982a, 1982b; Woosley & Weaver 1994; Woosley & Kasen 2011; Neunteufel et al. 2016, 2017; Ruiter 2020).

Double degenerate. Systems containing two WDs have been proposed as potential progenitors of thermonuclear SNe (Iben & Tutukov 1984; Webbink 1984; Fink et al. 2007, 2010; Pakmor et al. 2010; Sim et al. 2010; Kromer et al. 2010). Here mass transfer is invariably initiated through the effects of GWR, with simulations predicting either merging of the two WDs followed by a detonation (the "classical" double-degenerate mechanism) or dynamical ignition of the WD by the infalling matter stream. In the latter case, ignition may have to be catalyzed by the presence of an unburned layer of helium, either previously accreted during a post-CE mass-transfer phase (e.g., with the less massive donor in the state of an sdB star) or a remnant from other stages of stellar evolution prior to becoming a WD.

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