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# SUBSTELLAR SECONDARIES IN ZERO-AGE CATACLYSMIC VARIABLES

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RESUMEN

Se investiga la formación actual de variables cataclísmicas (CVs) con secundarias de enanas marrones (BD) utilizando la técnica de síntesis de población. En el código de síntesis de población se incorporaron resultados de los últimos modelos detallados para las BDs. Encontramos que CVs de edad cero (ZACVs) con secundarias BDs poseen períodos orbitales comprendidos en el intervalo 46 min – 2.5 horas, formando el 18% del total de la población actual de ZACVs. Por lo tanto encontramos que el 15% de la población actual de ZACVs debería tener períodos orbitales más cortos que el período orbital mínimo observado para CVs. Investigamos también la dependencia de la tasa actual de formación de CVs con secundarias BD con el valor asumido del parámetro de eficiencia de la envolvente común $\alpha_{CE}$, asumiendo tres distribuciones de cociente de masas diferentes para binarias ZAMS. Encontramos que el proceso de la envolvente común debe de ser extremadamente ineficiente ($\alpha_{CE} < 0.1$) como para que no se formen CVs con BD secundarias. Finalmente encontramos que las binarias progenitoras de ZACVs con secundarias BD poseen separaciones orbitales < 3AU y masas primarias entre 1 y 10 $M_\odot$ con 75% de las masas primarias menores que $\sim 1.6\ M_\odot$. Es interesante señalar que estos intervalos en separación orbital y masa primaria colocan a la mayoría de estas binarias progenitoras dentro del llamado "desierto de enanas marrones".

ABSTRACT

The present-day formation of cataclysmic variables (CVs) with brown dwarf (BD) secondaries is investigated using a population synthesis technique. Results from the latest, detailed models for BDs have been incorporated into the population synthesis code. We find that zero-age CVs (ZACVs) with BD secondaries have orbital periods in the range 46 min to 2.5 hrs, and that they comprise 18% of the total, present-day ZACV population. Consequently, we find that 15% of the present-day ZACV population should have orbital periods *shorter* than the observed orbital period minimum for CVs. We also investigate the dependence of the present-day formation rate of CVs with BD secondaries on the assumed value of the common envelope efficiency parameter, $\alpha_{CE}$, for three different assumed mass ratio distributions in ZAMS binaries. We find that the common envelope process must be extremely inefficient ($\alpha_{CE} < 0.1$) in order for CVs with BD secondaries not to be formed. Finally, we find that the progenitor binaries of ZACVs with BD secondaries have ZAMS orbital separations < 3 AU and ZAMS primary masses between $\sim$ 1-10 $M_\odot$, with $\sim$ 75% of the primary masses less than $\sim 1.6\ M_\odot$. Interestingly, these ranges in orbital separation and primary mass place the majority of the progenitor binaries within the so-called "brown dwarf desert."

*Key Words:* **BINARIES: CLOSE — NOVAE, CATACLYSMIC VARIABLES — STARS: BROWN DWARFS — STARS: EVOLUTION — STARS: LOW MASS**

## 1. METHOD

Of necessity, we must be brief here in our description of this investigation. For a detailed description of this study and its results, we refer the reader to Politano (2004).

The population synthesis code developed by Politano (1988; 1996) to model the formation of CVs has been modified for the purposes of this study. For a complete description of the code, we refer the reader to the original paper Politano (1996), and here only discuss the modifications made.

(1) We have developed a Monte Carlo version of the Jacobian code used by Politano (1988; 1996), and have used the Monte Carlo code in the present study. The Monte Carlo code contains the same physics as the Jacobian code, except as noted below, and it has been calibrated against the Jacobian code.

(2) The birthrate calculations of Politano (1996) were modified to include a more realistic treatment of the radius of the BD as a function of mass and age. This treatment comes from cooling curves of BDs produced by I. Baraffe and co-workers (Baraffe et al. 1998; 2003).

(3) For the calculation of the present-day orbital period distribution of ZACVs with BD secondaries,

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we have adopted an initial mass ratio distribution (IMRD) for the ZAMS progenitor binaries, g(q) dq = 1 dq, where q = secondary mass/primary mass. We emphasize though that, as in Politano (1988; 1996), we have assumed that the IMRD for binaries containing a ZAMS star and a BD *is the same* as the IMRD for binaries containing two ZAMS stars.

## 2. RESULTS

The results of the population synthesis calculations are shown in Figure 1 and Figure 2. In Figure 1, the present-day orbital period distribution of ZACVs is shown for the assumed choices, $\alpha_{CE} = 1$ and g(q) = 1. The subset of ZACVs that contain BD secondaries is shown in the dashed histogram. Our model predicts that CVs that are presently forming with BD secondaries occupy an orbital period range from 46 min to 2.5 hrs. We further predict that 18% of CVs at the present time are forming with BD secondaries. Of these, the majority ($\sim$ 80%) form below the orbital period minimum (78 min), with the remainder forming a tail reaching within the stellar domain. Thus, our model predicts that a *significant fraction*, ∼15%, of CVs are forming at orbital periods *shorter* than 78 minutes at the present time.

In Figure 2, the fraction of ZACVs that contain BD secondaries is plotted as a function of $\alpha_{CE}$, the common envelope efficiency parameter, for 3 different IMRDs: g(q) $\propto$ q, g(q) $\propto$ 1, and g(q) $\propto$ $q^{-0.9}$. Surprisingly, we find that *even for very small values* of the common envelope efficiency parameter ($\alpha_{CE}$ = 0.1), the fraction of CVs that form with BD secondaries is *not* zero. Rather, for $\alpha_{CE} = 0.1$, this fraction ranges from $\sim$ 3% to $\sim$ 18%, depending on the IMRD chosen.

## 3. CONCLUSIONS

We summarize our key findings and conclusions below:

(1) CVs that are presently forming with BD secondaries are predicted to occupy an orbital period range of 46 min to 2.5 hrs. This result is in substantial agreement with the previous result by Politano 1996. For the assumed choices of $\alpha_{CE} = 1$ and a mass ratio distribution in the ZAMS progenitor binaries, g(q) dq = 1 dq, our model predicts that a *significant fraction*, ∼15%, of CVs are forming with orbital periods *shorter* than 78 minutes at the present time.

(2) Assuming a constant CV birthrate throughout the Galaxy's history, the fraction of CVs that are presently forming below the period minimum according to our model, 15%, represents an upper limit

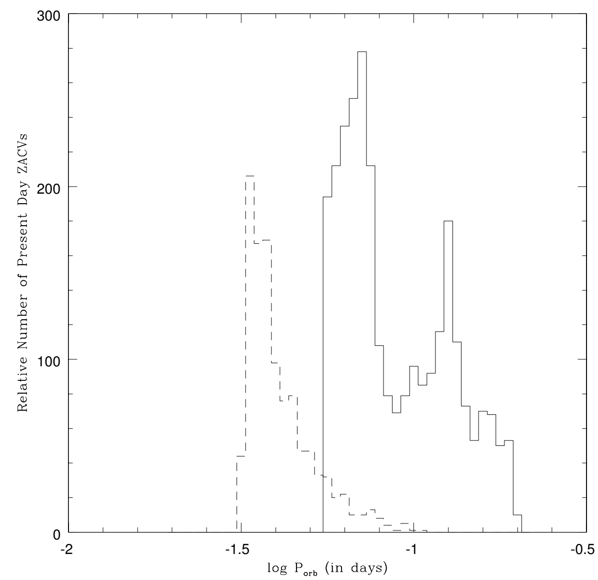


Fig. 1. The distribution of orbital periods in ZACVs. The dashed histogram shows systems that contain BD secondaries. The solid histogram shows systems that contain stellar secondaries.

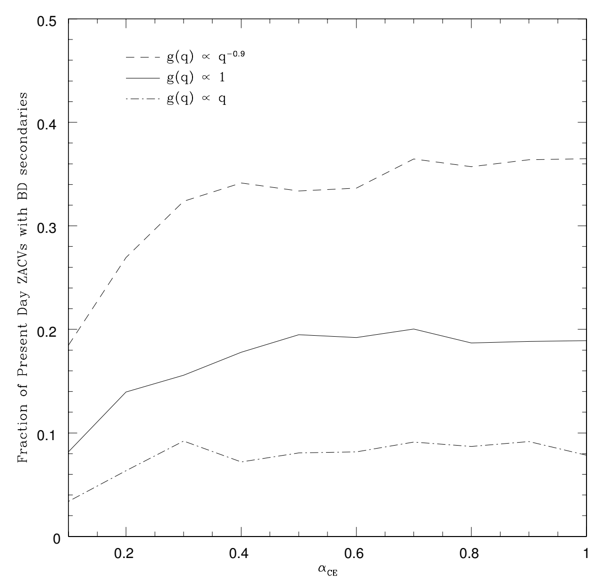


Fig. 2. The fraction of ZACVs that contain a BD secondary as a function of $\alpha_{CE}$ for three different IMRDs.

to the predicted fraction of *all* CVs with orbital periods less than 78 minutes at the present time. Of the $\sim$ 500 CVs with known orbital periods, 15% represents 75 systems. The number of CVs with orbital periods less than 78 minutes is currently two, V485 Cen and 1RXS J232953.9+062814, and it is dubious whether these systems contained substellar secondaries at birth. Thus, even with the recognition that 75 systems is an upper limit, the observed number of CVs in the period range 46 min–78 min is still *considerably less* than the number predicted by our models. It does not seem likely that the discrepancy is due to observational selection effects. The mass transfer rates and, hence, recurrence times, in CVs with BD secondaries below the period minimum should be very similar to systems like WZ Sge and AL Com (cf. Kolb & Baraffe 1999). Consequently, it is difficult to understand why we would not have observed outbursts in them.

(3) We have examined the dependence of the present-day formation of CVs with BD secondaries on the assumed value of the common envelope efficiency parameter, $\alpha_{CE}$. We find that even for values of $\alpha_{CE}$ as low as 0.1, CVs with BD secondaries are still able to be formed. A firm null result for the detection of CVs with BD secondaries having orbital periods less than 78 mins could therefore imply that the transfer of orbital energy into the common envelope is *extremely* inefficient for systems with very low-mass secondaries. Further, as it is unlikely that the CE process is that inefficient for the entire CV population, such a null detection would also then imply that the efficiency of the CE process is a function of secondary mass. If true, it would then seem extremely coincidental if $\alpha_{CE}$ decreases abruptly exactly at the substellar transition mass. Rather, one would expect that the decrease is smoother and begins in the *stellar* domain. Consequently, determining if there is a cutoff mass for the secondary, below which merger is inescapable, may have important implications for our theoretical understanding of the orbital period distribution in CVs below, and possibly within, the period gap.

(4) CVs that form with BD secondaries have evolved from progenitor ZAMS + BD binaries with primary masses in the range $\sim$ 1-10 $M_\odot$ and with orbital separations $<$ 3 AU, for an assumed IMRD that is flat (g(q) = 1). Furthermore, 75% of these progenitor systems have primary masses $\lesssim$ 1.6 $M_\odot$, and therefore spectral types F or later. The orbital parameter ranges in primary mass and orbital separation for these 75% coincide with the so-called "brown dwarf desert." then observations of ultra-short period CVs may be able to provide important clues regarding the formation and distribution of BD + MS in binaries with orbital separations less than 3 AU.

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