

Population types of cataclysmic variables in the solar neighbourhood

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Abstract

The Galactic orbital parameters of 159 cataclysmic variables in the Solar neighbourhood are calculated, for the first time, to determine their population types using published kinematical parameters. Population analysis shows that about 6 per cent of cataclysmic variables in the sample are members of the thick disc component of the Galaxy. This value is consistent with the fraction obtained from star count analysis. The rest of the systems in the sample are found to be in the thin disc component of the Galaxy. Our analysis revealed no halo CVs in the Solar vicinity. About 60 per cent of the thick disc CVs have orbital periods below the orbital period gap. This result is roughly consistent with the predictions of population synthesis models developed for cataclysmic variables. A kinematical age of 13 Gyr is obtained using total space velocity dispersion of the most probable thick disc CVs which is consistent with the age of thick disc component of the Galaxy.

Key words: 97.80.Gm Cataclysmic binaries, 98.10.+z Stellar dynamics and kinematics, 98.35.Pr Solar neighbourhood

1 Introduction

Cataclysmic variables (CVs) are short-period interacting binary stars, consisting of a white dwarf primary and a low-mass late spectral type secondary star. The secondary star fills its Roche lobe and transfers matter to the primary via a gas stream and an accretion disc. Accretion disc formation is prevented in

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systems with strongly magnetic white dwarfs in which mass accretion continues through accretion columns. For a detailed review of observational properties of CVs, see Warner (1995).

Stehle et al. (1997) studied the long-term evolution of cataclysmic variables as a function of the secondary star metallicity. They showed that Pop II CVs with a low metallicity secondary star have a detached phase with a smaller orbital period width, a shorter minimum period (Paczynski, 1967) and a slightly higher mass transfer rate, resulting in shorter evolutionary timescales compared to CVs where the secondary star has a Solar chemical composition. According to their population synthesis model, most Pop II CVs are expected to be found below the period gap (Verbunt & Zwaan, 1981; Rappaport et al., 1982, 1983; Paczynski & Sienkiewicz, 1983; Spruit & Ritter, 1983; King, 1988; Shao & Li, 2012). Stehle et al. (1997) express that the high γ velocities (systemic velocities or center of mass velocities) of some systems found by van Paradijs et al. (1996) suggest these systems to be Pop II CVs. However, most of these CVs are magnetic systems (DQ Her and AM Her stars), where the Doppler-shifts of spectral lines originate mainly from the accretion stream. Consequently, the errors in the γ velocities may be noticeably high. Still, finding magnetic systems below the period gap should not be a surprise as these systems concentrate towards shorter orbital periods, with little evidence for a period gap (Warner, 1995). Interestingly, this narrow (or none) period gap is consistent with the predictions from the study of Stehle et al. (1997). It should be noted that Ak et al. (2010) found magnetic systems to be much older than non-magnetic systems while they also emphasized doubts about the reliability of γ velocities obtained from the observations of magnetic systems.

Some CVs have been suggested to be the members of old populations in the Galaxy (Hawkins & Veron, 1987; Howell, Mitchell & Warnock III, 1987; Howell & Szkody, 1990; Drissen et al., 1994; Sheets et al., 2007; Uthas et al., 2011; Imamura & Tanabe, 2012). Clearly, it is hard to detect thick disc and halo CVs if they are not outbursting systems. CVs in globular clusters could be detected from their outbursts, emission lines, X-rays or their blue colours. Low metallicity values extracted from spectra can be another indicator for thick disc and halo CVs (Stehle et al., 1997). However, spectroscopic confirmation of these detections is difficult as they are very faint systems. For a detailed discussion on the detection of CVs in globular clusters, we refer to Knigge's (2011) review and references therein.

A reasonable observable sample of Pop II CVs (thick disc and halo CVs) can only be found at vertical distances from the Galactic plane $z \gtrsim 2$ kpc (Stehle et al., 1997). However, the faintness of CVs restricts most of their photometric and spectroscopic studies to the Solar neighbourhood. Although some abundance anomalies in UV and IR were found for CVs (Hamilton et al.,

2011; Gänsicke et al., 2005), there are no reliable metallicity measurements for CVs. In the absence of metallicity measurements, only kinematical and the dynamical methods are expected to provide reliable results in the recognition of the thick disc and halo CVs in the Solar neighbourhood. Although the development of sensitive CCD cameras, spectrographs and larger size telescopes made it possible to observe relatively faint CVs, we lack the necessary observational information to understand the kinematical properties of CVs in the Galactic scales.

In the next section we use the kinematical properties of 159 CVs in the solar neighbourhood to distinguish different Galactic populations among them.

2 The data

2.1 Input Parameters

The kinematical data used in this study are taken from Ak et al. (2010). The most important inputs used in their study are distances, γ velocities and proper motions. The proper motions of CVs were mostly obtained from the NOMAD Catalogue (Zacharias et al., 2005). The types, equatorial coordinates and orbital periods of CVs were mostly taken from Ritter & Kolb (2003, Edition 7.7) and Downes et al. (2001).

The distances were predicted using the PLCs relation of Ak et al. (2007). The PLCs relation is based on orbital period and Two Micron All Sky Survey (2MASS, Skrutskie et al., 2006) JHK_s photometric data (Cutri et al., 2003). This relation is reliable and valid in the ranges $0.032 < P(d) \leq 0.454$, $-0.08 < (J - H)_0 \leq 1.54$, $-0.03 < (H - K_s)_0 \leq 0.56$ and $2.0 < M_J < 11.7$ mag. For a detailed description of the method by the PLCs relation, we refer to Ak et al.'s (2007; 2008) studies. The distances obtained from this relation differ in general less than 4% from those obtained from trigonometric parallaxes (Gariety & Ringwald, 2012).

The last important inputs used in Ak et al. (2010) are the radial velocities which are used to calculate total space velocities. The radial velocity with respect to the Sun comes from measurements of Doppler-shifts in spectral lines. However, one has to take here into account that CVs are binaries, and thus one has to determine the radial velocity of the center of mass of the system. Ak et al. (2010) adopted the criteria defined by van Paradijs et al. (1996) when collecting γ velocities from the literature and merged these γ velocities with those collected by van Paradijs et al. (1996). Radial velocities, and consequently γ velocities, derived from emission lines are likely affected

by the motion in the accretion disc or the matter stream falling on the disc from the secondary. Thus, Ak et al. (2010) analyzed γ velocities statistically and looked for possible systematic errors in the γ values obtained from emission lines. They concluded that there is no substantial systematic difference between systemic velocities derived from emission and absorption lines and that the observed γ velocities can be reliably used for statistical analysis (see Ak et al., 2010, for details).

From the celestial coordinates (α, δ) , proper motion components $(\mu_\alpha \cos \delta, \mu_\delta)$, systemic velocity (γ) and the parallax (π), Ak et al. (2010) computed Galactic space velocities and their propagated errors with respect to the Sun using the algorithms and transformation matrices of Johnson & Soderblom (1987). Although the sampled CVs are relatively nearby objects, Ak et al. (2010) applied corrections for differential Galactic rotation to space velocities as described in Mihalas & Binney (1981). Ak et al. (2010) analyzed the propagated errors of space velocities, with respect to LSR (Local Standard of Rest), and refined their sample by removing systems with a total space velocity error $S_{err} > 30$ km s⁻¹. Although they collected input data from the literature for 194 CVs, this analysis decreased the number of usable systems in their sample to 159. In this study, the final sample of 159 CVs in Ak et al. (2010) is used to calculate the Galactic orbital parameters of systems.

2.2 Calculation of Galactic Orbits

In order to determine possible Galactic orbits of CVs, we first perform test-particle integration in a Milky Way potential which consists of a logarithmic halo of the form

$$\Phi_{\text{halo}}(r) = v_0^2 \ln \left(1 + \frac{r^2}{d^2} \right), \quad (1)$$

with $v_0 = 186$ km s⁻¹ and $d = 12$ kpc. The disc is represented by a Miyamoto-Nagai potential:

$$\Phi_{\text{disc}}(R, z) = - \frac{GM_d}{\sqrt{R^2 + \left(a_d + \sqrt{z^2 + b_d^2} \right)^2}}, \quad (2)$$

with $M_d = 10^{11} M_\odot$, $a_d = 6.5$ kpc and $b_d = 0.26$ kpc. Finally, the bulge is modelled as a Hernquist potential,

$$\Phi_{\text{bulge}}(r) = - \frac{GM_b}{r + c}, \quad (3)$$

using $M_b = 3.4 \times 10^{10} M_\odot$ and $c = 0.7$ kpc. The superposition of these components gives a good representation of the Milky Way. The circular speed at the Solar radius is taken ~ 220 km s $^{-1}$. The orbital period of the LSR is $P_{LSR} = 2.18 \times 10^8$ years while $V_c = 222.5$ km s $^{-1}$ denotes the circular rotational velocity at the Solar Galactocentric distance, $R_0 = 8$ kpc. The same formulae were already used to determine the Galactic orbits of objects from different classes, e.g. Coşkunoğlu et al. (2012) and Bilir et al. (2012).

In order to analyse Galactic orbits of CVs, the mean radial Galactocentric distance (R_m) is taken into account as a function of the stellar population and the orbital shape. We consider the planar and vertical orbital eccentricities, e_p and e_v , respectively. R_m is defined as the arithmetic mean of the final perigalactic (R_p) and apogalactic (R_a) distances, and z_{max} and z_{min} are the final maximum and minimum distances, respectively, to the Galactic plane whereas e_p and e_v are defined as follows:

$$e_p = \frac{R_a - R_p}{R_a + R_p}, \quad (4)$$

and

$$e_v = \frac{|z_{max}| + |z_{min}|}{R_m}, \quad (5)$$

respectively, where $R_m = (R_a + R_p)/2$ (Vidojević & Ninković, 2009). Due to z -excursions R_p and R_a can vary, however this variation is not more than 5%. Calculated orbital parameters of the 159 CVs are listed in Table 1. The columns of the table are organized as follows: name, equatorial (α, δ) coordinates, the final perigalactic (R_p) and apogalactic (R_a) distances, the maximum (z_{max}) and minimum (z_{min}) distances to the Galactic plane, total orbital angular momentum (J_z), and the planar (e_p) and vertical (e_v) orbital eccentricities. Apogalactic and perigalactic distances are determined from the averaged maximum and minimum galactocentric distances of systems in the calculated Galactic orbits within the integration time of 3 Gyr, i.e. backwards in time over an interval of 3 Gyr. This integration time is chosen to correspond to 12 or 15 revolutions around the Galactic center so that the averaged orbital parameters can be determined reliably.

2.3 Determination of Population Types

In order to determine the population types of the CVs, we define some dynamical and kinematical criteria. The criteria defined to select thick disc or

Table 1

The data sample. The table can be obtained electronically.

ID	Star	α (J2000.0) (hh:mm:ss)	δ (J2000.0) ($^{\circ}$: ' : '')	R_p (kpc)	R_a (kpc)	z_{min} (kpc)	z_{max} (kpc)	J_z (kpc km s $^{-1}$)	e_v	e_p
1	AR And	01:45:03.28	+37:56:32.7	7.894	8.207	-0.124	0.124	1790.1	0.015	0.019
2	LX And	02:19:44.10	+40:27:22.9	6.517	9.010	-0.150	0.150	1681.0	0.019	0.160
3	PX And	00:30:05.81	+26:17:26.5	7.001	9.804	-0.492	0.491	1815.7	0.058	0.167
4	RX And	01:04:35.54	+41:17:57.8	7.984	8.525	-0.128	0.128	1837.4	0.016	0.033
5	V603 Aql	18:48:54.64	+00:35:02.9	7.441	7.957	-0.081	0.081	1705.9	0.010	0.034
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halo CVs are as following:

- (1) The total space velocity (V_{tot}). Afşar et al. (2012) showed that stars with $V_{tot} \geq 100$ km s $^{-1}$ are thick disc or halo objects.
- (2) The relative probability for thick disc to thin disc membership (TD/D). Bensby et al. (2003, 2005) proposed that the stars with $TD/D > 1$ are thick disc or halo objects.
- (3) The maximum distance from the Galactic plane (z_{max}). It is well known that the thick disk is the dominant component of the Galaxy between 1 and 5 kpc above the Galactic disc while halo objects have z_{max} values larger than 5 kpc (Bilir et al., 2008).
- (4) Vertical orbital eccentricity (e_v). Bilir et al. (2012) concluded that vertical eccentricities of Galactic orbits calculated for the thick-disc and halo stars are larger than ~ 0.1 .
- (5) Planar eccentricity of the Galactic orbit (e_p). Using main-sequence stars, Pauli et al. (2003) found that stars with $e_p \gtrsim 0.3$ belong to the thick disc.

TD/D is calculated using a purely kinematical approach described by Bensby et al. (2003). These probabilities were estimated and listed by Ak et al. (2010). According to the criteria defined by Bensby et al. (2003) the stars are selected from four different TD/D intervals: $TD/D < 0.1$ (i.e. “high probability thin-disc stars”); $0.1 < TD/D < 1$ (i.e. “low probability thin-disc stars”); $1 < TD/D < 10$ (i.e. “low probability thick-disc stars”) and $TD/D > 10$ (i.e. “high probability thick-disc stars”). So, in this study a possible thick disc or halo CV is expected to fulfill at least two of these criteria.

Using the criteria defined above, we find that nine of 159 CVs in the sample belong to thick disc population. The rest of the sample consists of thin disc systems. It is concluded that there are no halo CVs, as the maximum distances to the Galactic plane z_{max} of the CVs in the sample do not exceed 5 kpc. Thick disc CVs found in this study are listed in Table 2 with their total space velocities (V_{tot}), with respect to LSR, types, orbital periods (P_{orb}), and the maximum distances to the Galactic plane (z_{max}). The relative probability

Table 2

Probable thick disc CVs in the sample. Remarks indicate the fulfilled criteria as defined in the text.

Star	Type	P_{orb} (hr)	V_{tot} (km s ⁻¹)	Criteria					Remark
				(1)	(2)	(3)	(4)	(5)	
J2050-0536	NL, AM	2.299	100.55	14.5	0.46	0.038	0.381	1, 2, 5	
VV Pup	NL, AM	1.674	151.63	9602	0.54	0.036	0.511	1, 2, 5	
BY Cam	NL, AM	3.354	142.74	1064	0.80	0.060	0.456	1, 2, 5	
CT Ser	N	4.680	80.58	0.2	1.00	0.145	0.243	3, 4	
V1043 Cen	NL, AM	4.190	80.59	8.3	1.03	0.102	0.229	2, 3, 4	
J1629+2635	NL	2.033	72.11	2.5	1.04	0.112	0.184	2, 3, 4	
IY UMa	DN, SU	1.774	114.73	70	1.39	0.148	0.284	1, 2, 3, 4	
J0813+4528	DN, UG	6.936	78.34	0.5	1.77	0.189	0.198	3, 4	
AK Cnc	DN, SU	1.562	154.72	36015	2.26	0.195	0.413	1, 2, 3, 4, 5	

DN: dwarf novae, NL: nova-like stars, N: novae, SU: SU UMa type dwarf novae, UG: U Gem type dwarf novae, AM: AM Her (polars) type nova-like stars.

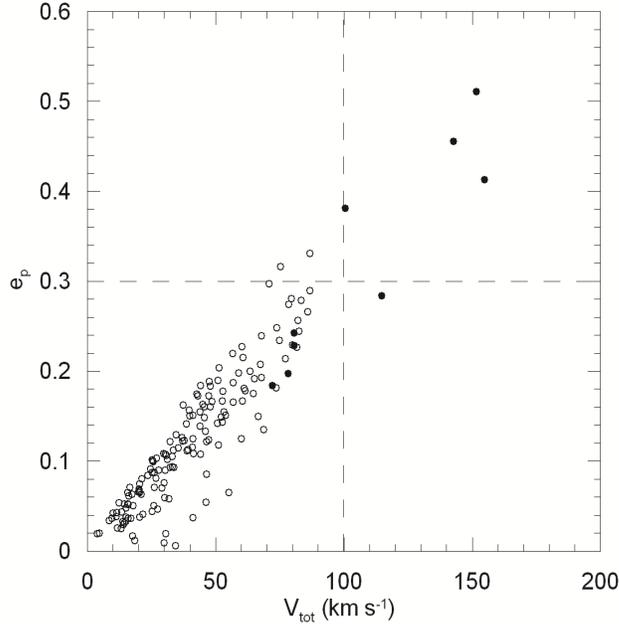


Fig. 1. V_{tot} - e_p diagram for the CVs in the sample. Thick disc and thin disc objects are indicated with filled and empty circles, respectively. Dashed lines represent limit values of criteria defined in the text.

for the thick disc to thin disc membership (TD/D) is also listed in the Table 2. e_p and e_v are planar and vertical eccentricities of the Galactic orbits, respectively. In Figs. 1-3, nine thick disc CVs are indicated in V_{tot} - e_p , e_p - e_v and e_p - J_z diagrams of the CV sample in this study, respectively.

AK Cnc is the most probable thick disc CV in the sample. This object fulfills all the criteria we defined above. IY UMa is also one of the strongest thick

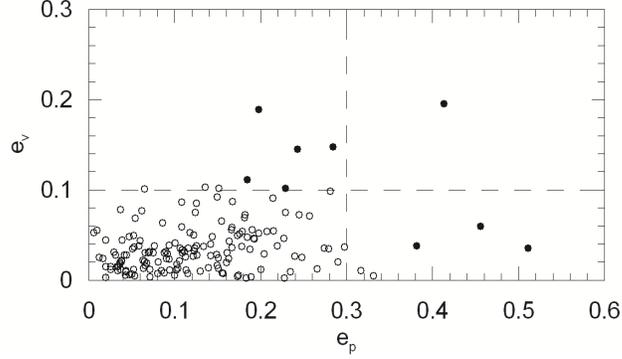


Fig. 2. e_p - e_v diagram for the CVs in the sample. Symbols and dashed lines are as in Fig. 1

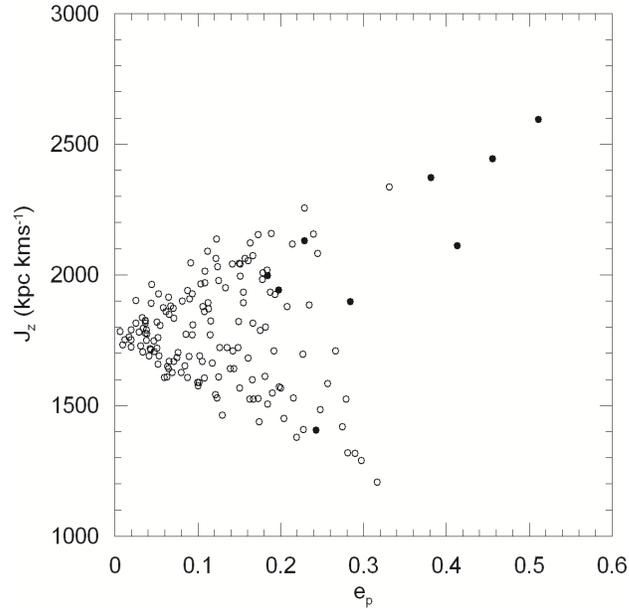


Fig. 3. e_p - J_z diagram for the CVs in the sample. Symbols are as in Fig. 1

disc candidates of CVs. IY UMA accomplishes four criteria but one: the planar eccentricity of its Galactic orbit is 0.284 which is very close to 0.3 (see, Fig. 3). VV Pup, BY Cam and J2050-0536 accomplish three criteria: $V_{tot} \geq 100$ km s^{-1} , $TD/D > 1$ and $e_p \gtrsim 0.3$ for these CVs (see, Fig. 2). For J1629+2635 and V1043 Cen, we found $TD/D > 1$, $z_{max} \gtrsim 1$ kpc and $e_v \gtrsim 0.1$. CT Ser and J0813+4528 match with two criteria. We found $z_{max} \gtrsim 1$ kpc and $e_v \gtrsim 0.1$ for these two systems. AK Cnc, IY UMa, VV Pup, BY Cam and J2050-0536 were already suggested to be thick disc objects by Ak et al. (2010) using a pure kinematical approach. Our results is consistent with this suggestion.

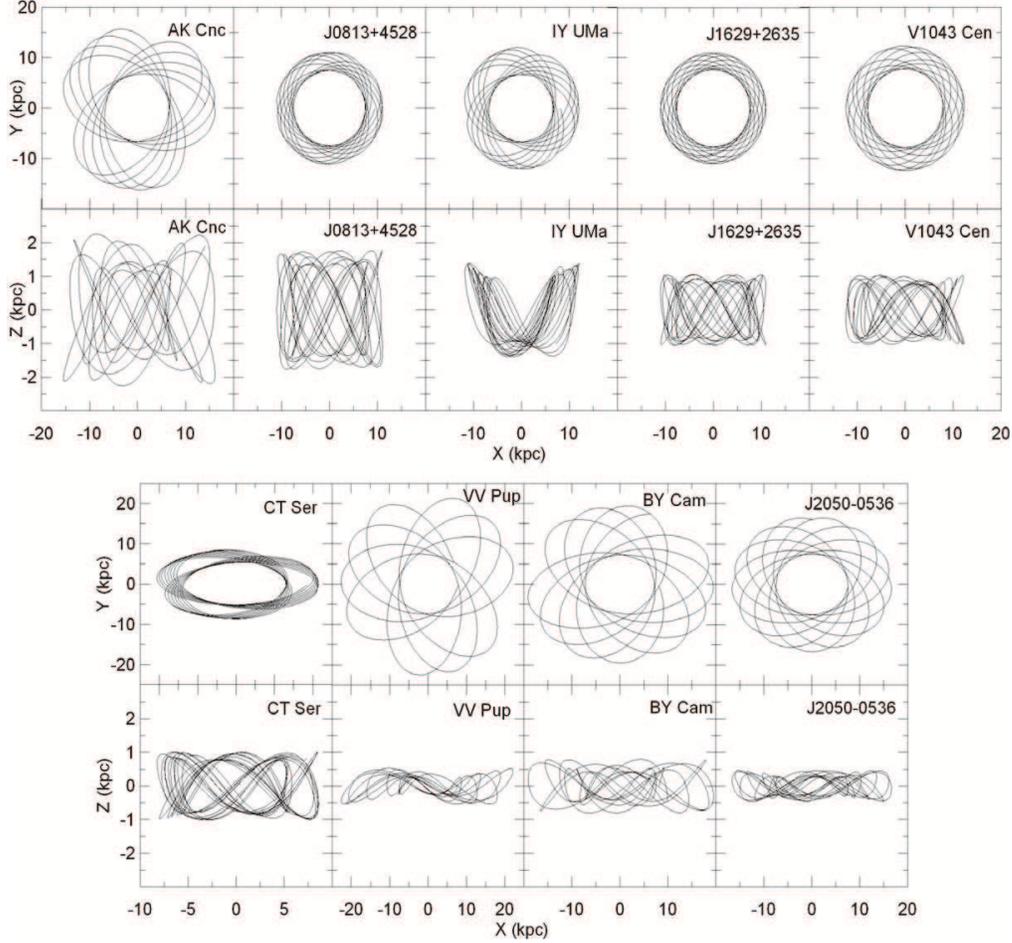


Fig. 4. Galactic orbits of the thick disc CVs found in this study projected onto $X - Y$ and $X - Z$ planes. Galactic orbits are calculated for an integration time of 3 Gyr.

3 Conclusion and discussions

In this study we calculated, for the first time, the Galactic orbital parameters of a large number of CVs. We also determined their population types using these calculations and the kinematical parameters as found by Ak et al. (2010)

Our analysis shows that almost all of the CVs in the sample are in the thin disc component of the Galaxy. Only nine CVs in the sample are thick disc stars. These objects are listed in Table 2. These are the CVs which cross the Galactic disc through their Galactic orbits. The Galactic orbits of these systems as projected on to $X - Y$ and $X - Z$ planes are shown in Fig. 4. Galactic orbits of the thick disc CVs in Fig. 4 were calculated for an integration time of 3 Gyr, corresponding to 12-15 revolutions around the Galactic center. As the maximum distances from the Galactic plane (z_{max}) in Table 2 are not larger than 5 kpc, we conclude that there are no halo objects in the sample.

It is found that the fraction of thick disc CVs to thin disc CVs in the sample is $\sim 6\%$ which is in very good agreement with the fraction of Pop II field stars to Pop I field stars in the Solar neighbourhood (Robin et al., 1996; Buser et al., 1999; Bilir et al., 2006). This suggests that our CV sample is complete for the Solar neighbourhood. So, we conclude that statistical studies using this sample give reliable and self-consistent results.

Ak et al. (2010) found that the middle point of the period gap is at 2.62 hr for the objects in the sample. An inspection of the thick disc CVs in Table 2 reveals that $\sim 60\%$ of thick disc CVs are located below the orbital period gap. According to the population synthesis model of Stehle et al. (1997), most Pop II CVs are expected to be found below the period gap. We conclude that the calculated fraction of thick disc CVs below the period gap to the thick disc systems above the period gap in this study is roughly consistent with the theoretically expected fraction. It is also interesting to note that $\sim 45\%$ of thick disc CVs found in this study are magnetic systems (AM Her stars).

Some CVs have already been suggested to be the members of old populations in the Galaxy. Objects proposed to be Pop II CVs in Howell, Mitchell & Warnock III (1987), Drissen et al. (1994), Sheets et al. (2007), Uthas et al. (2011) and Imamura & Tanabe (2012) are not included in our sample. Howell & Szkody (1990) list 84 known or good candidates for being halo CVs by selecting high Galactic latitude objects. Although 21 of them are included in our sample, only one of them (AK Cnc) is identified as a thick disc CV in this study. It must be emphasized that the Galactic latitude is not a reliable indicator for the population type of an object. Our analysis shows that the most probable thick disc CVs in Table 2 have high Galactic angular momentums, implying that they are in a population different than the thin disc (Fig. 3). As thick disc and halo objects have eccentric orbits, they can pass through the Solar neighbourhood during their nuclear evolution. That is why the analysis of Galactic orbits is very important in the determination of population types.

The dispersion of the total space velocities is an indicator of population types, as the velocity dispersion of a group of objects is related to their kinematical age. The total space velocities of the six systems with $z_{max} \gtrsim 1$ kpc in Table 2 were taken from Ak et al. (2010) and the dispersion of the total space velocities is calculated as 101 km s^{-1} . Using the equation given by Wielen (1977) and Wielen et al. (1992), the kinematical age of the six most probable thick disc CVs in the sample is calculated as 13 Gyr. This value is consistent with the age of the thick disc population in the Galaxy (Feltzing & Bensby, 2008).

Our study shows that there are thick disc CVs in the Solar neighbourhood. Our study also implies that halo CVs, if they are present, must be very rare in the vicinity of the Sun. Kinematical studies can reliably prove their presence. However, current γ velocity measurements are mostly dubious. That is

why we emphasize the importance of radial velocity studies of CVs. Further observational data can help to find more thick disc or halo CVs. Specially, investigations based on the data obtained from deep sky surveys could help to find more Pop II CVs. Detailed observations of these systems could give clues for their evolution.

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