The age of cataclysmic variables

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ABSTRACT

Applying standard models for formation and evolution of cataclysmic variables (CVs) we determine the age structure of a model population of Galactic CVs. By convolving the obtained CV age distribution with the observed age–space velocity relation of single stars we derive the theoretically expected distribution of γ–velocities and the dispersion of γ as a function of orbital period. This dispersion turns out to be essentially independent of selection effects. Therefore the observational determinination of γ for a sufficient number of CVs with known orbital period would probe the intrinsic, largely invisible CV population. Our model calculation predicts that most systems above the period gap are younger than 1.5 Gyr, whereas systems below the gap have a typical age of 3–4 Gyr. This age difference is a direct result of disrupted magnetic braking and leads to a significant difference between the velocity dispersion of CVs below and above the period gap; however observations do not at present support the existence of this significant difference, although the data is sufficiently sparse and uncertain that it does not contradict it either.

Key words: novae, cataclysmic variables — binaries: close — stars: evolution — stars: kinematics

1 INTRODUCTION

At present the sample of cataclysmic variables (CVs) with determined orbital period P comprises ~ 270 systems (Ritter & Kolb 1995, 1996). The period is the most easily measured global parameter of a CV relevant for the study of CV evolution: P changes on the mass transfer timescale, and the distribution of CVs over P provides clues on their origin and evolution (e.g., King 1988). Although standard models of CV formation and evolution can be easily combined to a model for the Galactic CV population (see the recent reviews by Kolb 1995, 1996) the final link to observed distributions like the period histogram with its well–known "period gap" depends crucially on a proper representation of observational selection effects which determine the observed sample. Approximating the observed ensemble of systems with determined orbital period as an incomplete visual magnitude–limited sample satisfactorily reproduces gross features of the observed period histogram (Kolb 1995, Stehle, Kolb & Ritter 1996). A similar procedure for the distribution of the white dwarf mass M_1 (e.g., Kolb 1993b) appears to fit the observations fairly well, but the relatively small number of systems with estimated M_1 (less than a quarter of the systems in Ritter & Kolb 1996) and uncertainties involved in an observational determination of M_1 permit only very limited constraints on the theoretical models. The situation is worse for the mass transfer rate, the determination of which requires knowledge of the system's distance. Similarly, the independent determination of the secondary mass (not relying on an assumed mass–radius relation) is difficult.

Recently, van Paradijs, Augusteijn & Stehle (1996) have drawn attention to another collective property of CVs, the distribution of space velocities, as a means of probing the age profile of the CV population. Applying the age–velocity dispersion relation found empirically for nearby single stars (e.g., Wielen 1977, Freeman 1993) to CVs allows one to identify the dispersion in space velocities with the dynamical age of the population, the time elapsed since formation of the ZAMS progenitor binary.

As we shall show below the age of a system in the present CV population is largely determined by the timescale of magnetic stellar wind braking and gravitational wave radiation, the orbital angular momentum loss mechanisms driving the post common envelope evolution (e.g., King 1988). The essential ingredient of standard CV evolutionary models to explain the period gap is disrupted magnetic braking (Spruit & Ritter 1983, Rappaport et al. 1983), according to which the much faster magnetic braking does not operate in systems with a fully convective mass donor. An immediate consequence is that the average age of CVs above the period gap must be significantly smaller than the average age below the gap. We confirm this qualitative expectation by using population synthesis methods. In addition, our models show that brightness–dependent observational selection effects preserve the age difference, so that the observational determination of the CV velocity dispersion as a function of orbital period would directly probe the intrinsic population of CVs and provide an independent test of disrupted magnetic braking.

Unfortunately, deducing γ, the radial velocity of the system's centre of mass, from the observed radial velocity curve of a CV is subject to large uncertainties. These arise mainly because internal motion in the accretion disk or stream typically contribute much higher velocities than γ. The danger of misinterpretation is particularly high for γ–velocities obtained from emission lines, and in magnetic systems, where very high non–symmetrical velocities along the accretion stream confuse the situation.

Nevertheless, van Paradijs et al. (1996) compiled a list of published γ–velocities and find that magnetic CVs indeed show a significantly higher dispersion in γ than non–magnetic CVs, whereas γ values determined from emission lines appear to be consistent with those determined from absorption lines. Moreover, they obtain a dispersion of γ which is comparable with the velocity dispersion of late–type single main–sequence stars, and conclude that CVs have an average age of $3\,10^9$ Gyr.

Sec. 2 briefly reviews main concepts of the model for CV evolution and formation and gives a discussion of the predicted time–dependent formation rate of CVs. The resulting age structure of the synthesized Galactic CV population is presented in Sec. 3. In Sec. 4 we apply the age–velocity dispersion relation to deduce the CV velocity disperion as a function of orbital period, and confront the model prediction with the sample compiled by van Paradijs et al. (1996). A critical discussion concludes the paper.

2 THE TIME–DEPENDENT CV BIRTHRATE

In order to deduce information on the expected velocity dispersion we require knowledge about the age distribution of systems in the present CV population. We derive this information within the framework of standard CV formation and evolution models (see e.g. Kolb 1995, 1996):

Briefly, CVs form from much wider main–sequence binaries with a low–mass main–sequence secondary. The initial orbital period $P_{\rm i}$, typically $10 - 1000$ days, is such that the more massive primary (with mass $M_{\rm p} \simeq 1M_\odot - 9M_\odot$) fills its Roche lobe when it has a deep convective envelope on the giant branch or asymptotic giant branch (AGB). The ensuing mass transfer is dynamically unstable, leading to a common envelope (CE) configuration where dynamical friction efficiently extracts angular momentum and energy from the orbit to eject the giant's envelope. If enough orbital energy was available, the giant's exposed core, the future dwarf (WD), survives in a close pre–CV system with the secondary almost unaffected (e.g. Iben & Livio 1993 for a review on CE evolution). The pre–CE evolution time is given by the primary's nuclear timescale, roughly

$$t_{\rm nuc} \simeq 10^{10} \left(\frac{M_{\rm p}}{M_\odot}\right)^{-3} {\rm yr}\,, \qquad (1)$$

whereas the time spent in the CE itself presumably is very short, of order 10^3 yr. After the CE the detached system approaches the semi–detached state by either nuclear expansion of the secondary, or by loss of orbital angular momentum, e.g. gravitational radiation and magnetic braking. We consider here CVs with low-mass secondaries $M_2 \lesssim 1 M_\odot$ where nuclear evolution is slow and can be neglected. Then the time $t_{\rm preCV}$ spent in the pre–CV state is the time needed to shrink the orbit from the post–CE period $P_{\rm f}$ (typically $0.1 - 10$ days) to the period $P_{\rm sd} \simeq 9{\rm h} m_2$ at onset of mass transfer as a CV, i.e. when the secondary's stellar radius equals the Roche radius

$$r_{\rm L} \simeq 1.94\, m_2^{1/3} P_{\rm d}^{2/3} \quad \text{for } m_1 \gtrsim m_2 \qquad (2)$$

(m_1 and m_2 denote the WD and secondary mass in solar units, $r_{\rm L}$ the secondary's Roche radius in solar units, and $P_{\rm d}$ the orbital period in days). This shrinkage proceeds on the orbital angular momentum loss timescale $t_{\rm J}$, i.e.

$$t_{\rm GR} = -\left(\frac{J}{\dot J}\right)_{\rm GR} = 3.8 \times 10^{11} \frac{(m_1+m_2)^{1/3}}{m_1 m_2} P_{\rm d}^{8/3}\ {\rm yr} \qquad (3)$$

for the case of gravitational radiation (GR), and

$$t_{\rm MB} = -\left(\frac{J}{\dot J}\right)_{\rm MB} = 2.2 \times 10^{9} \frac{m_1}{(m_1+m_2)^{1/3}} r_2^{-4} P_{\rm d}^{10/3}\ {\rm yr} \qquad (4)$$

(r_2 is the secondary's radius in solar units) for magnetic braking in the formulation of Verbunt & Zwaan (1981), with the radius of gyration set to $(0.2)^{1/2}$ and the calibration parameter to unity. For Eq. (4) we assumed that the secondary's spin is tidally locked to the binary orbit, even when the secondary does not yet fill its Roche lobe. Note that the pre–CV time $t_{\rm preCV}$ can be *much shorter* than either (3) or (4) if the system emerges from the CE almost semi–detached ($P_{\rm f} \simeq P_{\rm sd}$): if $t_{\rm J} =$ const. $\times P^n$ then $t_{\rm preCV} = (t_J(P_{\rm f}) - t_J(P_{\rm sd}))/3n$.

Once semi–detached the evolution is driven by angular momentum losses, as before, and the mass transfer time is determined by (3) and (4) with the additional constraint that the secondary has to fill its Roche lobe, $r_2 = r_{\rm L}$. For our considerations we apply the disrupted magnetic braking model where magnetic braking is assumed to operate only for CVs whose secondaries have a radiative core, i.e. for $M_2 \gtrsim 0.2 - 0.3 M_\odot$ (see, e.g., King 1988). The same assumption holds for pre–CVs.

Population synthesis models (e.g. de Kool 1992, King et al. 1994) show that pre–CE evolution on average is short compared to detached post–CE evolution, i.e. that the primary's nuclear timescale $t_{\rm nuc}$ is short compared to $t_{\rm preCV}$. This is obvious as long as systems emerge from the CE with a period $P_{\rm f}$ long compared to $P_{\rm sd}$ (hence $t_{\rm preCV} \simeq t_{\rm J} \gtrsim t_{\rm nuc}$). However, post–CE binaries cover a wide range of $P_{\rm f}$ (cf. Fig. 3 in King et al. 1994), and for many systems $P_{\rm f}$ is close to $P_{\rm sd}$. Such systems spend a time much shorter than either (3) or (4) in the detached post–CE configuration. But in this case also $t_{\rm nuc}$ is short because they must have evolved from a progenitor binary with the most massive primary consistent with the

WD's mass: the initial (pre–CE) period $P_{\rm i}$ is essentially given by the WD mass M_1, as this is the core mass of the giant immediately before the CE, when the giant's Roche lobe radius equals the stellar radius, which in turn is determined by the core mass. For given $P_{\rm i}$ and M_1, the post–CE period $P_{\rm f}$ is the shorter the more massive the giant's total mass $M_{\rm p}$ is (as more orbital energy is needed to eject a more massive envelope).

Similarly, although progenitors of low–mass WD systems (He WDs) are low–mass giants with a rather long $t_{\rm nuc}$, almost all of them end up as slowly evolving GR driven (pre–)CVs. This is because mass transfer stability in CVs requires the mass ratio $q = M_2/M_1$ to be small, thereby excluding high–mass secondaries with a radiative core. Hence again $t_{\rm nuc} \lesssim t_{\rm preCV}$ in this case.

In view of all this it is clear that newborn CVs fall essentially into two groups: those with a fully convective secondary and those with a more massive secondary where magnetic braking is effective. The latter group evolves rapidly, cf. (4), and is in equilibrium with newly forming ZAMS progenitor binaries after $\simeq 10^9$ yr. Low-mass systems evolve much more slowly, cf. (3), and attain such an equilibrium only after a time comparable to the age of the Galaxy, see e.g. Fig. 8 of de Kool (1992).

As a consequence the CV formation rate is time–dependent even if the underlying star formation rate (SFR) is constant and the relative distribution of progenitor binaries over ZAMS binary parameters remains unchanged. In fact, the difference of evolutionary timescales (3) and (4) completely dominates the appearance of such a time–dependent CV formation rate, and a slight variation of the SFR does not change the CV birth rate significantly. Only if the period of star formation is restricted to a short, early phase after Galaxy formation (as is the case for population II CVs, see Stehle, Kolb & Ritter 1996) does the short magnetic braking timescale $t_{\rm MB}$ cause a marked depletion of systems above the period gap. However, as population I CVs dominate the CV population anyway we restrict our analysis to the simple case of a constant SFR throughout the Galactic history.

Further parameters of the model calculations presented below are the same as in Stehle, Kolb & Ritter (1996), i.e. a time–independent Miller & Scalo type distribution both for primary and secondary mass, and a flat distribution in $\log P_{\rm i}$. The common envelope efficiency was set to 1, and during the CV stage all transferred mass was assumed eventually to leave the system with the WD's specific orbital angular momentum. We chose $T_{\rm G} = 10^{10}$ yr for the age of the Galaxy. For further details on the population synthesis method we refer to Stehle, Kolb & Ritter 1996, Politano 1996, Kolb 1993, and deKool 1992.

3 AGE DISTRIBUTION

The main results of our model computations are shown in Figs. 1 and 2. We plot the distribution function of a visual magnitude ($m_{\rm vis}$) limited sample taken from the theoretical model of the present CV population over orbital period P and age t of the individual systems in Fig. 1. Here "age" means the time elapsed since formation of the corresponding main–sequence progenitor binary, i.e. the sum of pre–CE evolution time ($\simeq t_{\rm nuc}$), pre–CV time $t_{\rm preCV}$ and time elapsed since turn–on of mass transfer as a CV. The visual magnitude–limited sample was obtained by applying the selection factor $L_{\rm vis}^{3/2} \simeq M_1^{3/2}\dot{M}^{9/8}$, thought to approximate bolometric corrections for a stationary optically thick accretion disk with mass accretion rate $\dot{M}$ around a WD with mass M_1 (details are given by Stehle, Kolb & Ritter 1996). From this figure the distinction between the young CVs above the gap and the older CVs below the gap becomes obvious. Figure 2 shows the relative age distribution of the same $m_{\rm vis}$–limited sample for systems above the gap (dotted line) and below the gap

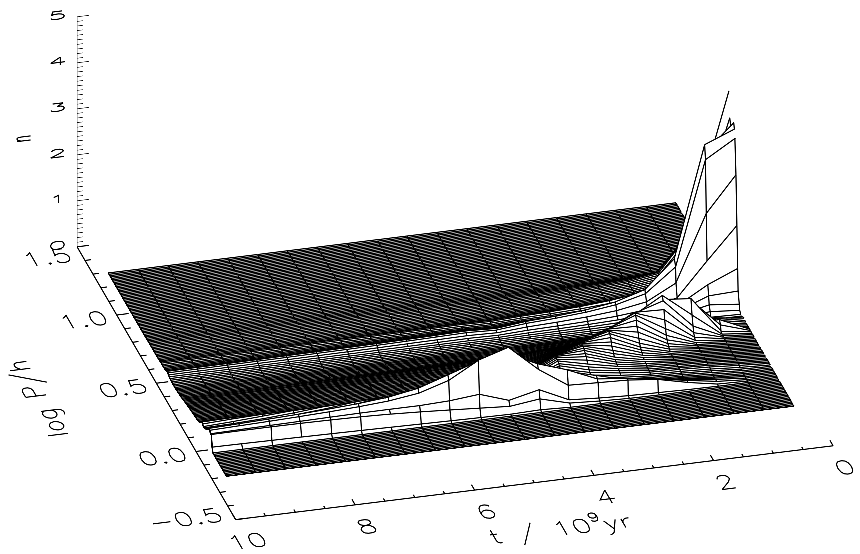

Figure 1. The relative number $n(\log P, T)$ of CVs in a $m_{\rm vis}$–limited sample as a function of binary orbital period P and age t in arbitrary normalization. CVs below the period gap peak in number at an age of 3–5 Gyr, whereas most CVs above the period gap are younger than 1.5Gyr.

(dashed line), obtained by integrating the results displayed in Fig. 1 over the corresponding range of P. The full line in Fig. 2 represents the fraction of systems of a given age which are above the gap. Both in Fig. 1 and 2 the age binning is 0.5 Gyr. As a result the minimum time needed to form a CV is not resolved (strictly we have $n \to 0$ for $t \to T_{\rm G}$).

4 γ–VELOCITIES AS INDICATOR FOR THE AGE OF CVS

In the previous sections we investigated the age distribution of the observable CV population using population synthesis models. We now ask if the model prediction that CVs with long orbital periods ($P \gtrsim 3$ h) are significantly younger than CVs with short orbital periods ($P < 2$ h) can be tested against observations.

4.1 Transformation of age into γ–velocities

By sampling nearby disk stars of different age with determined space velocity it was shown (see e.g. Wielen 1977, Carlberg et al. 1985; and Wielen et al. 1992, Freeman 1993 for recent reviews) that the dispersion of the peculiar space velocity increases with stellar age t. This observed age–velocity relation is believed to result from the diffusion of stellar orbits induced by dynamical interaction with massive objects (such as giant molecular clouds or massive black holes). As older stars had more time to interact gravitationally with this irregular component of the Galactic potential they show a larger velocity dispersion.

The velocity dispersion σ is defined as the root mean square (r.m.s) of the peculiar stellar space velocity $\boldsymbol{v}$ in a local Galactic coordinate system (U, V, W), where U points towards the Galactic centre, V in the direction of the Galactic rotation and W to the north Galactic pole.

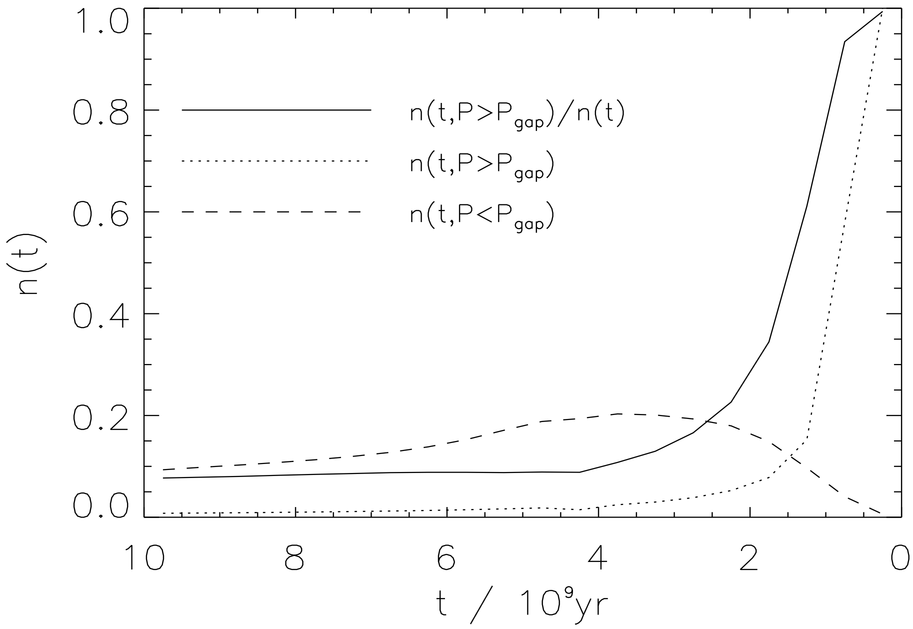

Figure 2. The relative number of systems in a $m_{\rm vis}$–limited sample as a function of age for CVs above the period gap (dotted line) and CVs below the gap (dashed line). The full line represents for the same sample the fraction of CVs of a given age which lie above the period gap.

Wielen (1977), revisited by Wielen et al. (1992), finds for the total dispersion $\sigma_{\rm v}$ defined by

$$\sigma_{\rm v}^2 = \sigma_{\rm V}^2 + \sigma_{\rm U}^2 + \sigma_{\rm W}^2 \tag{5}$$

the following relation

$$\sigma_{\rm v} \simeq \left(10 + 21.5 \left(\frac{t}{10^9 {\rm yr}}\right)^{1/2}\right) {\rm km\ s}^{-1} . \tag{6}$$

We expect this relation to hold also for binaries unless the systems undergo a violent evolutionary phase involving asymmetric ejection of a significant fraction of the total mass with high velocity. Such kick velocities could be caused e.g. by asymmetrical emisson of neutrinos in supernovae. CV progenitors indeed eject most of their mass during the common envelope phase (see Sec. 2), but the associated timescale is long compared to the binary period, and the expansion velocity the envelope material attains is small, typically of order $\lesssim 100$ kms^{-1}, less than the orbital velocity (see e.g. Iben & Livio 1993). Therefore the ejection process can be regarded as symmetrical about the binary rotation axis, and the CE phase does not alter the system's space velocity.

During the semi–detached CV phase the space velocity may additionally be affected by the cumulative effect of repeated nova explosions with possibly asymmetric envelope ejection. This (or any other such evolutionary process) would *increase* the velocity dispersion of CVs during their evolution. Then Eq. (6) would underestimate $\sigma_{\rm v}$.

Using the age–velocity relation (6) we translate the age of a CV in the population model into the corresponding space velocity dispersion. The characteristic velocity observed for a number of CVs is the radial velocity of the binary's centre of mass, the γ–velocity. As most observed CVs are in the very vicinity of our Sun they can be regarded as isotropically

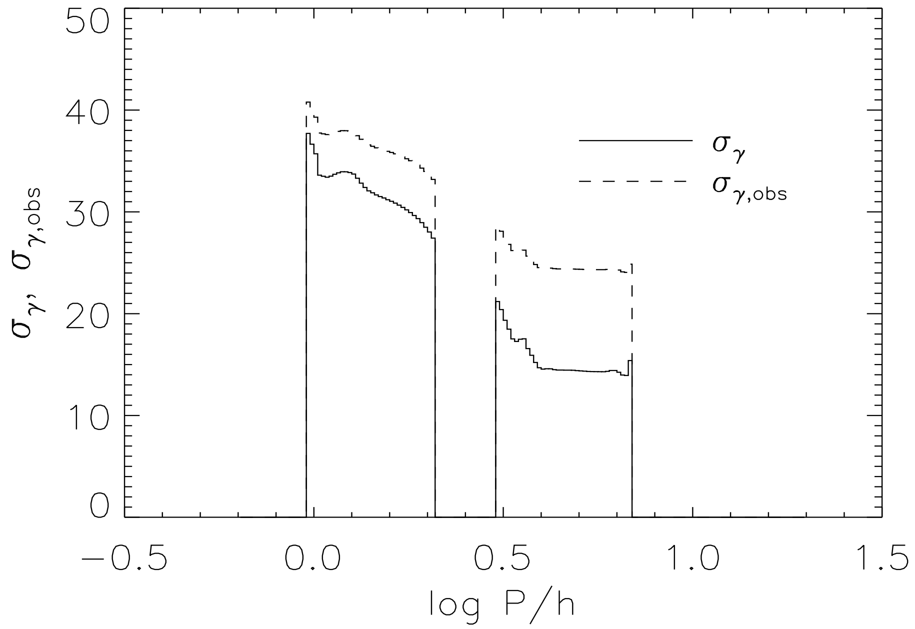

Figure 3. The intrinsic velocity dispersion σ_γ as a function of orbital period P (full line). The dashed line represents the expected velocity dispersion $\sigma_{\gamma,\rm obs}$ when typical observational errors are taken into account.

distributed, and the γ–velocity dispersion $\sigma_{|\rm v|}$ is related to $\sigma_{\rm v}$ via

$$\sigma_{|\rm v|}^2 =< \gamma^2 >= \frac{1}{3}\sigma_{\rm v}^2. \tag{7}$$

The transformation of the CV distribution $n(t,P)$ over system age t and orbital period P (shown in Fig. 1) to the distribution $n(\gamma,P)$ over radial space velocity γ and P is accomplished by

$$n(\gamma,P) = \int_0^{T_{\rm G}} n(t,P)\,{\rm disp}(t)\,{\rm d}t\,, \tag{8}$$

where we choose for disp(t) : $t \to \gamma$ a normalized Gaussian function

$${\rm disp}(t) = \frac{1}{\sqrt{2\pi}\sigma_{|\rm v|}(t)} \exp\left(-\frac{1}{2}\frac{\gamma^2}{\sigma_{|\rm v|}^2}\right)\,, \tag{9}$$

with $\sigma_{|\rm v|}$ given by (6) and (7). From $n(\gamma,P)$ we derive for each orbital period P the r.m.s. σ_γ of the range of γ–velocities at this orbital period. The resulting function $\sigma_\gamma(P)$ is shown in Fig. 3 as a full line. As expected (young) CVs above the period gap show a significantly smaller dispersion in γ than (old) systems below the period gap.

At this point it is important to realize that the relation $\sigma_\gamma(P)$ shown in Fig. 3 is essentially *independent* of selection effects which determine the distribution $n(\gamma,P)$ from which $\sigma_\gamma(P)$ was derived. In fact, as demonstrated in Fig. (4), we obtain effectively *the same* relation when we repeat the above analysis with the distribution $n(t,P)$ describing the intrinsic CV population, i.e. the total population of all CVs in the Galaxy, instead of starting from the observable magnitude limited sample.

This finding can be understood as follows: for a given P all systems, irrespective of their age, have to first order the same (secular mean) mass transfer rate $\dot M$ and therefore the same brightness — a property ultimately caused by the presence of an attracting solution in the

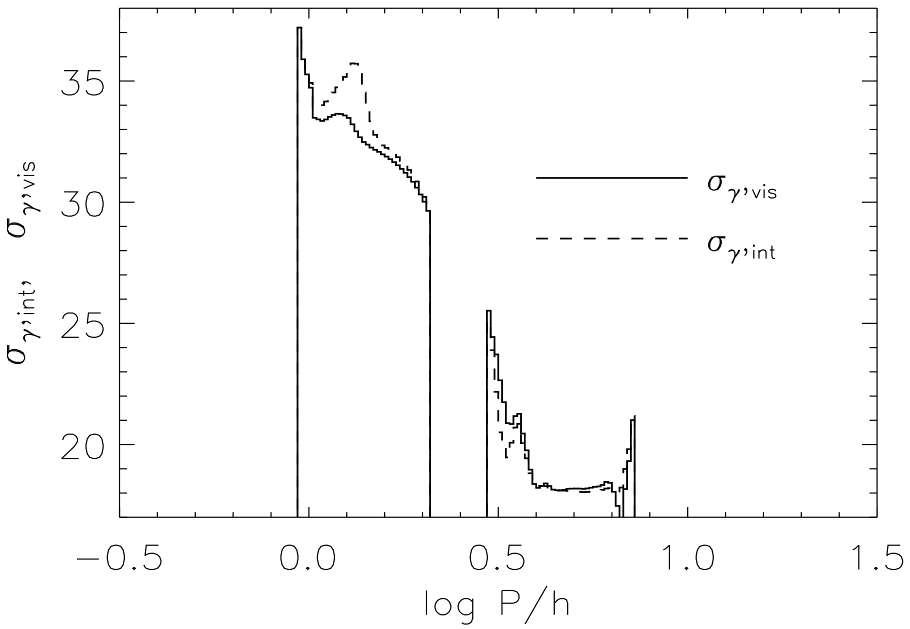

Figure 4. The intrinsic velocity dispersions σ_γ for the intrinsic CV population (dashed line) and for the magnitude limited sample drawn from this population (full line). Note the restricted plot range of the σ_γ axis.

differential equations governing the evolutionary behaviour (Stehle, Ritter & Kolb 1996). Thus any brightness–dependent selection effect affects systems of any age at a given P in the same way, and the relative age distribution at P remains the same. This remains true even if the full spectrum of WD masses at given P is taken into account: The WD has an effect on the accretion luminosity $L_{\rm accr} \propto M_1 \dot{M}/R_1$ both directly via its mass M_1 and radius R_1 determining the depth of the gravitational potential, as well as indirectly via the angular momentum loss term $\dot{J}/J$ determining the accretion rate $\dot{M}$. The population models show that any resulting age–sensitive selection effect (WDs with different mass have a different average age) is negligible. More generally speaking, $\sigma_\gamma(P)$ is insensitive to any selection effect which is age–independent. Mass transfer cycles which seem to be superimposed on the evolutionary mean mass transfer rate and give rise to a scatter in $\dot{M}$ at a given P (King et al. 1995, 1996) belong to this category, as well as the dwarf nova recurrence time.

Unfortunately the uncertainties in the observational determination of γ mentioned above give rise to a measurement error that is usually not small compared to the intrinsic γ–velocity. The main problem in deriving accurate values for γ from observed Doppler shifts is the deconvolution of centre of mass motion and orbital motion. Van Paradijs et al. (1996) estimate this uncertainty from 34 systems where multiple measurements from different studies were available. They find $\sigma_{\rm obs} \simeq 20$ km s^{-1} for the r.m.s. scatter of a single γ measurement in non–magnetic CVs. As long as $\sigma_{\rm obs}$ is independent of the intrinsic dispersion both can be added quadratically to yield the total observed dispersion:

$$\sigma^2_{\gamma,\rm obs} = \sigma^2_{\rm obs} + \frac{1}{3}\sigma^2_\gamma. \tag{10}$$

The resulting function $\sigma_{\gamma,\rm obs}(P)$ is shown in Fig. 3 as a dashed curve. There is still an obvious decrease of the velocity dispersion with orbital period.

We finally note that any possible rapid increase of the system's space velocity caused by a single intrinsic evolutionary event would add quadratically to the time–dependent dispersion

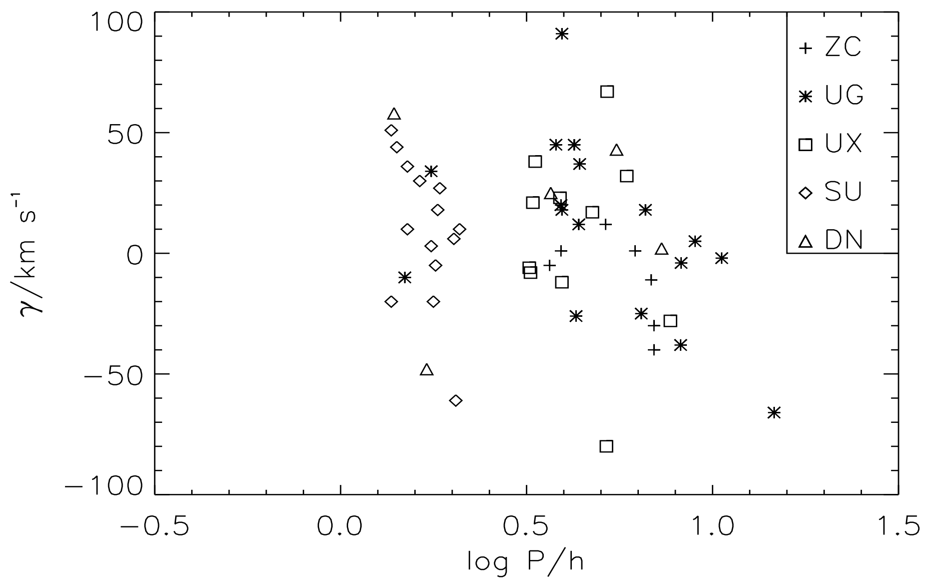

Figure 5. Measured γ–velocities for non–magnetic CVs, collected by van Paradijs et al. (1996). Different symbols indicate different CV subtypes. The spread in γ has to be compared to the dashed line in Fig.3.

in γ and would increase $\sigma_{\gamma,\mathrm{obs}}$ further by introducing another additive term in (10). The observed dispersion of γ corrected for the observational uncertainty is small, $\sigma_\gamma \sim 25 - 30$ km s^{-1} (van Paradijs et al. 1996), very close to the values predicted by the model which relies on the observed age–velocity relation for single stars. Hence we conclude that for CVs and CV progenitors there is no evolutionary phase with significant effect on the binary's space velocity.

4.2 Comparison with observations

For all non–magnetic CVs in the list compiled by van Paradijs et al. (1996) we plot in Fig. 5 γ as a function of orbital period P. Different symbols represent different CV subtypes. The spread in γ at a given P should be compared with the corresponding theoretically predicted velocity dispersion $\sigma_{\gamma,\mathrm{obs}}(P)$ at the same P, shown in Fig. 3 as a dashed curve. Apparently the data do not support the prediction that systems below the gap have a significant larger velocity dispersion than systems above the gap. However, given the uncertainties intrinsic to the data we feel that a conclusive observational verification or falsification of our model prediction must await a more accurate determination of γ (with an uncertainty of only a few km/s) for a larger number of systems.

5 DISCUSSION

We investigated the age profile of the observed sample of cataclysmic variables by population synthesis methods. The standard model of formation and evolution of CVs predicts a clear age difference between systems above and below the period gap. The former comprise very young systems, typically formed less than $\lesssim 1.5$ Gyr ago, while the latter represent a much older population, dominated by systems which formed $\simeq 3$ Gyr ago. The main reason for this dichotomy is that magnetic braking is thought to operate only when the secondary is massive enough to retain a radiative core. Systems with a fully convective secondary (corresponding to CVs below the gap) are driven by gravitational radiation only. Our population synthesis shows that the pre–common envelope evolution is typically much too short to prevent these very different post common envelope evolutionary timescales from leaving a significant mark on the CV population.

Observations of nearby stars indicate that the dispersion of peculiar space velocity increases with stellar age. We apply the age–velocity dispersion relation found by Wielen et al. 1992 to predict the CV's velocity dispersion $\sigma_\gamma(P)$ as a function of orbital period. According to our models the dispersion of γ–velocities is $\sigma_\gamma \simeq 15$ km s^{-1} above the period gap, and $\sigma_\gamma \simeq 30$ km s^{-1} below the gap. Observational selection is largely brightness–dependent, and the luminosity of CVs with the same orbital period should be the same, whatever the age (except for systems beyond the minimum period). Consequently $\sigma_\gamma(P)$ is effectively independent of observational selection. Hence it directly probes a property of the intrinsic CV population most of which is hidden from our view.

There is some controversy about the precise shape of the age–velocity dispersion relation. However, for a test of our most important finding, the different age of CVs below and above the period gap, by velocity measurements we just require that the velocity dispersion of young systems ($t \lesssim 1$ Gyr) is significantly different (smaller) than the dispersion of systems with an age $t \simeq 3$ Gyr. The observational data suggest that the age–velocity dispersion relation has indeed this property, even though there is no agreement about the relation for higher ages, where some authors claim to detect a plateau due to saturation of the diffusion effects (see, e.g., the discussion in Freeman 1993).

Therefore we believe that a careful determination of γ for a sufficient number of CVs above and below the period gap could provide a powerful test of the most fundamental ingredient of the standard model for CV evolution: disrupted magnetic braking.

The presently available set of observationally determined γ–velocities for non–magnetic CVs (compiled by van Paradijs et al. 1996) shows no significant dependence of the spread in γ on orbital period and appears to be in conflict with interrupted magnetic braking. However, the determination of γ is subject to large uncertainties merely from the fact that internal orbital motions in the binary are usually much faster than the centre of mass motion; γ values obtained by different authors for the same CV show an intrinsic dispersion which adds quadratically to the theoretical prediction, thereby reducing the difference between the dispersion above and below the period gap. In fact, the uncertainty quoted by van Paradijs et al. (r.m.s. scatter $\simeq 20$ kms^{-1}) is larger than the predicted value for σ_γ above the period gap. For these reasons we believe that a verification or falsification of our model prediction — and hence a serious test of disrupted magnetic braking — must await an improved set of observed γ–velocities.

In contrast, with typically $\gamma \lesssim 50$ km s^{-1}, the observations *do* show that CV progenitors cannot be subject to intrinsic evolutionary phases leading to a substantial change of their space velocity, as expected from the current formation models describing CV formation.

In principle, the observed values for γ should be corrected for differential Galactic rotation before a comparison with our model. But as van Paradijs et al. (1996) note, given the value $A \simeq 15$ km s^{-1} kpc^{-1} for the Oort constant, these corrections are negligible in view of the small average distance of CVs ($\simeq 300$ pc). Similarly, systems above the gap are brighter and therefore on average at larger distances than systems below the gap, but both models and observations show that this is a negligible effect and can not account for the lack of a σ_γ difference between systems which are below and above the period gap.

If future observations fail to reveal the predicted velocity difference, i.e. confirm what the present sample suggests, there would be no immediate need to abandon the disrupted magnetic braking picture for *semi–detached* evolution (which would leave the explanation for the CV period gap completely open). Rather it is mainly the extension of magnetic braking to the *detached* post–CE evolution of systems with non–fully convective secondaries which imprints the age structure found in the model population. As mentioned above magnetic braking extracts orbital angular momentum only if the secondary's spin is tidally locked to the orbit. The efficiency of synchronizing torques for wide systems is still a matter of debate (see e.g. the discussion in Shore 1994), and it appears conceiveable that the orbital evolution time at long post–CE periods might be much longer than (4) suggests. This would in fact increase the mean age of CVs above the gap. Alternatively, the CE itself could terminate at orbital periods very different from the ones obtained in our population models by the standard energy estimates; see e.g. the suggestion in Yorke, Bodenheimer & Taam (1995) and Terman & Taam (1996).

To conclude we emphasize again that a more stringent test of disrupted magnetic braking must await more precise data, and we strongly encourage further observational work in this direction.

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