Optical observations of close binary systems with a compact component
Augusteijn, T.

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Outline of a comparative study of disk and halo cataclysmic variables


Abstract

We have selected samples of dwarf novae, on the basis of their magnitudes in outburst which represent disk and halo populations. We give a short discussion of our selection criteria. Of the 59 sources in our halo sample, only 6 have accurately known orbital periods. Our primary aim is to increase the number of Population II dwarf novae with known orbital periods through a search for photometric variability of orbital origin such as eclipses, hot-spot humps and/or ellipsoidal or heating effects in the secondary. By comparing the orbital period distribution and space densities of our two samples we hope to gain a better understanding of the formation and evolution of cataclysmic variables.

10.1 Introduction

A cataclysmic variable (CV) consists of a Roche-lobe filling, late-type secondary which transfers mass to a white-dwarf primary. The general evolution from the detached binary, or pre-CV, to the semi-detached state of a CV, and the subsequent long-term evolution to shorter orbital periods is thought to be driven by orbital angular momentum losses caused by gravitational radiation and magnetic braking (see, e.g., King 1988). Although the evolution of the semi-detached CV phase seems to be fairly well understood, the formation rate and preceding evolutionary path of pre-CVs is not well known.

A standard technique in the study of stellar evolution is to compare groups of stars that are distinguished by their spatial distribution (halo/disk), age or kinematics. We want to apply this general method to CVs, by comparing the period distribution and space density of Population I and Population II CVs. Population II CVs are expected to have relatively uniform high age and low metallicity (see, however, Stehle and Ritter 1994). By comparing the two groups, we expect to obtain information on the formation and evolution of (pre-)CVs, and perhaps such other aspects of CV evolution as the physics of magnetic braking, the effect of metallicity on accretion, the outburst mechanism of dwarf novae, the period gap and the minimum period.

Recent population synthesis of CVs, including CV–birthrates, their secular evolution and selection effects, were able to explain the general features of the observed period distribution of CVs (Kolb and Ritter 1992). Within a similar model Stehle et al. (1994) made a prediction for the period distribution of Population II CVs, but for this population a reliable observed sample is still lacking.
10.2 Halo and disk CVs

To study and compare the properties of Population I and Population II CVs we have started a project to determine the orbital period distribution of comparable samples of "halo" and "disk" dwarf nova type CVs. Our primary goal is to obtain a sample of high galactic latitude CVs (HGL-CVs) which have a high probability to be different in their evolutionary history from galactic disk CVs.

We selected our halo sample in the following way:

- we limit our sample to dwarf novae
- we use the magnitude in outburst as distance indicator
- the sources have $z > 400$ pc
- the sources have $b > 20^\circ$

For comparison, we selected a control group of galactic disk CVs with $d > 400$ pc, but $z < 190$ pc.

10.3 Discussion of the selection criteria

Dwarf novae

There are many problems in selecting a well defined sample of CVs for which to determine the orbital period distribution. There is a large variety of types of CVs distinguished by their eruptive behavior (novae, dwarf novae), the magnetic field strength of the white dwarf primary (polars and intermediate polars), or their spectral properties (nova-like variables). Any sample including different types will be biased because of the different ways in which the sources are discovered; e.g., polars and intermediate polars are mainly discovered in X-rays. However, also the photometric behavior in quiescence can play an important role in the resulting period distribution; e.g., UX UMa type CVs (a subgroup of the nova-like variables) generally do not show regular photometric variations with their orbital period, and only for those sources that show eclipses can the orbital period be determined easily. A further problem is posed by the need of a good distance indicator for the sources.

Selecting only dwarf novae circumvents many of the problems mentioned above. There is a fairly large number of known dwarf novae which form a relatively well defined homogeneous group of CVs. Furthermore, dwarf novae generally show regular photometric variations with the orbital period. Dwarf novae in outburst are fairly bright in outburst, and they can be identified out to large distances. The brightness in outburst can also be used to estimate the distance to the sources (see below).

Distance estimate using the magnitude in outburst

Warner (1987) found that the intrinsic visual brightness of dwarf novae in outburst is, in contrast to quiescence, well constrained (the peak magnitudes show a weak, but well-behaved dependence on orbital period). Szkody and Howell (1992; see also Sect. 10.4) found that some dwarf novae which have large amplitude outburst are intrinsically faint in quiescence. Also these sources have absolute visual magnitudes in outburst which are consistent with Warner's result (see Sect. 10.5). Furthermore, the magnitude of a dwarf nova in outburst is a much better defined observational quantity than the magnitude in quiescence.

As we do not know the orbital period a priori we have taken the average absolute visual magnitude for dwarf novae in outburst $M_V(\text{out}) = 4.7$ mag (Vogt 1981; see also Warner 1987).
As we will obtain more information about the sources that are included in our sample (e.g., the orbital period, the inclination) we will reassess their inclusion in the sample. We also plan to use (near) infra-red observations to attempt to detect the secondary and derive an independent estimate for the distance to the sources which can be used to check our selection criteria.

\( z > 400 \text{ pc} \)

Allen (1976) gives the z-distance for Population II stars as starting at 400 pc. For the CVs in the thin galactic disk the scale height is \( H^I \approx 190 \text{ pc} \) (Patterson 1984). The space distribution of Population II stars is spread out to much higher distances above the galactic plane. This halo population has a (possibly somewhat flattened) spheroidal shape were the density is a function of the distance to the galactic center (see, e.g., Freeman 1987). For simplicity we will here assume a Gaussian distribution as function of \( z \) with a scale-height equal to that of the thick galactic disc (intermediate Population), where \( H^{II} \approx 1500 \text{ pc} \) (Freeman 1987).

By taking a Gaussian distribution in the \( z \) direction

\[
n^{I,II}(z) = n_0^{I,II} \exp \left\{ - \left( \frac{z}{H^{I,II}} \right)^2 \right\}
\]

and a relative population of \( n_0^{II}/n_0^I \approx 0.02 \) (Freeman 1987) we derive a probability at \( z = 400 \text{ pc} \) for a CV to be a member of the Halo of \( P(z=400 \text{ pc}) = 60\% \). (Note, however, that this estimate only applies to the intrinsic population and not to the observed population. The observational selection effects on the Population I and Population II CVs, which contribute to the population of CVs [at a given height above the galactic plane], could be very different; see Stehle and Augusteijn 1995).

After deriving the \( z \)-distance from observations we plan to make a probability-weighted sample using the probability

\[
P(z) = \frac{n_0^I}{n_0^{II}} \exp \left\{ \left( \frac{z}{H^{II}} \right)^2 - \left( \frac{z}{H^I} \right)^2 \right\}
\]

\( b > 20^\circ \)

One potential problem in selecting sources at large distances is that the sources can be significantly reddened, which results in over-estimating their distances. However, the galactic absorption layer is concentrated towards the galactic disk, and the sources in our halo sample are largely unaffected. Only sources which are at low galactic latitudes are expected to be affected significantly. We, therefore, have limited our halo sample to sources with \( b > 20^\circ \). At a galactic latitude of 20° the average extinction is expected to be 0.2 mag (Woltjer 1975), which affects the selection of our sources only slightly.

The control group

One of the difficulties of studying a sample of halo sources is to take a properly selected control group of disk sources. Most of the disk dwarf novae which have been studied in any detail have much brighter apparent magnitudes than the sources in our sample of halo, or HGL-CVs, and the observational selection effects on the two samples may be very different (see, e.g., Ritter and Burkert 1986, Dünhuber 1993). We, therefore, selected a second sample of dwarf novae which are at a distance of more than 400 pc and is limited by \( z < 190 \text{ pc} \). Thus, we have not included sources between approximately 1 and 2 scale heights to distinguish the two populations as clearly as possible.
Table 10.1 Halo dwarf novae selected from the General Catalogue of Variable Stars

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* UBVI = Johnson UBVI; v = visual; p = photographic; r = red; j = SRC j (unfiltered IIIa-j)
# UG= Dwarf Nova; UGSS= SS Cyg type Dwarf Nova; UGSU= SU UMa type; UGZ= Z Cam type
$^{sh}$ Period estimated from superhump period
$^{\odot}$ Own determination
Table 10.2 Disk dwarf novae selected from the General Catalogue of Variable Stars

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Discussion of the selection criteria.
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* UBVI = Johnson UBVI; v = visual; p = photographic; r = red; j = SRC j (unfiltered IIIa-j)
# UG=Dwarf Nova; UGSS=SS Cyg type Dwarf Nova; UGSU=SU UMa type; UGZ=Z Cam type
sh Period estimated from superhump period © Own determination
References to Tables 10.1 and 10.2.

10.4 Our sample

From the GCVS (Kukarkin 1990; see Downes and Shara 1993) we have selected 261 dwarf novae that are fainter than $m_V = 12.7$ in outburst, i.e., more distant than 400 pc. Our halo sample is limited to those sources with $z > 400$ pc and $b^I > 20^\circ$. Our disk sample is delineated by $z < 190$ pc. Thus, we have not included sources with $z$ between 1 and 2 scale heights, to distinguish the two populations as clearly as possible. In this way we have selected a total of 59 halo, and 127 disk dwarf novae.

The number of sources in our halo sample is about the same as the number of dwarf novae included in the sample of halo CVs by Howell and Szkody (1990; see also Szkody and Howell 1992). These authors also selected their sources from the GCVS, and their sample was limited to those sources with $z > 350$ pc and $b^I > 40^\circ$. They, furthermore, excluded sources with outburst amplitude smaller than 1.9 mag. The major differences with the halo sample presented here is that the distance estimates were based on the magnitudes in quiescence (see Sect. 10.5). As a result of the differences in selection criteria, of the 57 dwarf novae as ‘halo’ CVs in the sample of Howell and Szkody only 27 are included in our sample.

In summary:

“Halo”: \( z > 400 \text{ pc} \) ; \( b > 20^\circ \) \hspace{1cm} 59 sources

“Disk”: \( d > 400 \text{ pc} \) ; \( z < 190 \text{ pc} \) \hspace{1cm} 127 sources

In Tables 10.1 and 10.2 we list the sources in our halo and disk sample, respectively. In these tables we list for each source the position, the magnitudes in outburst and quiescence, the classification, the galactic latitude, the period (if known), and some comments including the observed photometric variations and some relevant references; in the last column we indicate if the source has already been observed in our programme.

In the future we hope to extend our samples as more sources, particularly at high galactic latitude (see, e.g., Drissen et al. 1994), are detected. An additional benefit of our project will be that we extend the number of all CVs with known orbital period to fainter magnitudes, which is expected to reduce the bias of the presently known sample towards high mass white dwarf CVs (Ritter and Buckert 1986, Dünhuber 1993).

10.5 High Galactic Latitude CVs revisited

Howell and Szkody (1990; see also Szkody and Howell 1992) were the first to attempt a comprehensive study of HGL–CVs. They noted that a different CV population might be observed at high galactic latitudes and that studying HGL–CV might give us new insight into the birth rates and into the secular evolution of CVs. The orbital period distribution of their sample was found to be weighted towards short periods and the outbursts of dwarf novae have on average larger amplitudes than ‘disk’ dwarf nova. Also, for several of these ‘halo’ dwarf novae, the intrinsic brightness in quiescence was found to be substantially lower than that of ‘disk’ dwarf novae.

The dwarf novae included in the sample of HGL–CVs of Howell and Szkody (1990) were selected on the basis of their magnitudes in quiescence. From a study of dwarf novae with known distances Warner (1987) found that the absolute visual magnitude of dwarf novae in quiescence is a, roughly linear, function of orbital period. As the orbital periods were not known they assumed a priori an average absolute visual magnitude in quiescence of $M_{qui} = 7.5$ mag, and
Figure 10.1. The expected absolute magnitude in quiescence, $M_{\text{qul}}(z=350 \, \text{pc})$, if the dwarf novae taken from the sample of Howell and Szkody were placed at a distance of 350 pc above the galactic plane, as a function of orbital period. The drawn line gives the relation between the absolute magnitude in quiescence and the orbital period derived by Warner (1987). The dashed line shows the same relation shifted upward by 0.7 mag, which reflects the rms value of the individual points around this relation. See the text for the meaning of the different symbols.

Included those sources with distances $z$ above the galactic plane greater than 350 pc. Here we re-examine the inclusion of those dwarf novae in the sample of HGL–CV of Howell and Szkody (1990) for which the orbital period has been measured. In Fig. 10.1 we show the expected absolute magnitude in quiescence, $M_{\text{qul}}(z=350 \, \text{pc})$, if the dwarf novae taken from the sample of Howell and Szkody were placed at a distance of 350 pc above the galactic plane; i.e. the lower limit for these sources to be included in the sample. In this figure sources below $M_{\text{qul}}(z=350 \, \text{pc}) = 7.5$ are included in the sample of Howell and Szkody.

In Fig. 10.1 we also indicate:

- those sources which are included in our sample (squares)

- the relation between the absolute magnitude in quiescence and the orbital period derived by Warner (1987; drawn line). Sources below this line are expected to be at a distance greater than 350 pc above the galactic plane

- the same relation shifted upward by 0.7 mag (dashed line), corresponding to the rms deviation of the individual points around the relation derived by Warner

- those sources that show eclipses in their light curve (indicated with a plus sign). As one observes the accretion disk under a large angle these sources appear substantially fainter.
than expected from a source with the average absolute brightness, and their distance will be over-estimated. This difference is a strong function of inclination, and can be as large as $\sim 3$ mag (see, e.g., Warner 1987)

- sources which have large, $\Delta \geq 5.7$ mag, outbursts (filled in symbols). For some of these sources Szkody and Howell (1992) have found that they are exceptionally faint in quiescence (see Sect. 10.6).

From Fig. 10.1 we conclude that the dwarf novae in the sample of Howell and Szkody (1990) are likely to be heavily contaminated with disk CVs.

We also identify several other potential problems with this study: i) The selection of dwarf novae as members of the halo was based on distance estimates assuming an average absolute magnitude in quiescence. As Howell and Szkody found themselves, this assumption is not valid (see also Van Paradijs 1983, Warner 1987). ii) Each source was initially observed for 2–4 hrs, and re-observed only if it showed any indication of a possible periodic variation. This results in a strong bias towards shorter periods. iii) The control group consisted of disk CVs which are much brighter than the 'halo' sample, and the observational selection effects on the two groups may be very different (see Ritter and Buckert 1986, Dünhuber 1993).

### 10.6 Large-amplitude dwarf novae

In Table 10.3 we give for some dwarf novae which have large-amplitude outbursts the absolute magnitude in quiescence, as estimated by Szkody and Howell (1992). In this table we also show the amplitude of the outburst and the resulting absolute magnitude in outburst. In the next column we give the absolute magnitude in outburst calculated from the relation by Warner (1987) between the absolute magnitude in outburst and the orbital period. For the two sources which do not have a measured orbital period we list the range in absolute magnitude expected from this relation for periods in the range 80 min to 6 hrs. In the last two columns we give estimates of the distance above the galactic plane as derived from the observed apparent magnitudes using the average magnitude in quiescence (as used by Howell and Szkody 1990) and the average magnitude in outburst ($M_V = 4.7$; Vogt 1981), respectively.

<table>
<thead>
<tr>
<th>Source</th>
<th>$M_V$(qui) (mag)</th>
<th>Ampl. (mag)</th>
<th>$M_V$(out) (mag)</th>
<th>$M_V^{est}$(out) (mag)</th>
<th>$z$ estimate in pc</th>
</tr>
</thead>
<tbody>
<tr>
<td>BC UMa</td>
<td>11.0–13.5</td>
<td>7.4</td>
<td>3.6–6.1</td>
<td>5.25</td>
<td>1310</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>157</td>
</tr>
<tr>
<td>WW Cet</td>
<td>&lt;9.4–12.0</td>
<td>5.7</td>
<td>&lt;3.4–6.0</td>
<td>4.55</td>
<td>351</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>79</td>
</tr>
<tr>
<td>VZ Aqr</td>
<td>10.5–12.0</td>
<td>5.9</td>
<td>4.6–6.1</td>
<td>4.1–5.3</td>
<td>512</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>123</td>
</tr>
<tr>
<td>AK Cnc</td>
<td>10.4–11.9</td>
<td>5.9</td>
<td>4.5–6.0</td>
<td>4.1–5.3</td>
<td>1010</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>242</td>
</tr>
</tbody>
</table>

For all sources the derived absolute magnitudes in outburst are consistent with the relation by Warner (1987) and the average magnitude in outburst derived by Vogt (1981). We further note that the distance estimates using the magnitude in outburst are systematically smaller than using the magnitude in quiescence, which indicates that the former method to select halo CVs is more conservative independent of the validity of either assumption.
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