On the implications of the period distributions of subclasses of cataclysmic variables

Frank Verbunt

Astronomical Institute, University of Utrecht, Postbus 80000, NL-3508 TA, Utrecht, The Netherlands

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ABSTRACT

The period distributions of dwarf novae and nova-like variables above the period gap are different if the VY Scl systems are classed with the nova-like variables, but the same when the VY Scl phenomenon is classed with the dwarf nova outbursts. For the remaining nova-like variables, the period gap is no longer significant. Classification of the VY Scl phenomenon with dwarf novae suggests that dwarf nova outbursts are caused by variation in mass transfer from the donor. Absence of the period gap obviates the need for models explaining it, and invalidates one piece of evidence for the importance of magnetic braking for the evolution of cataclysmic variables and of low-mass binaries in general.

Key words: binaries: close – stars: evolution – novae, cataclysmic variables.

1 INTRODUCTION

The orbital period of a low-mass system in mass transfer provides important clues to the nature of the mass donor, and accordingly the distribution of orbital periods sets significant constraints on models describing the evolution of such systems. A notable feature in the period distribution of cataclysmic variables is the relative dearth of systems with orbital periods in a range between roughly 2 and 3 h, the so-called 'period gap'. Numerous observational studies have dramatically increased the number of known orbital periods for cataclysmic variables in the last decade, and in this paper use is made of the increased statistics to investigate the period distributions of various subclasses of these binary systems separately.

The data for the investigation are taken from the compilation by Ritter & Kolb (1995) and are shown in Fig. 1. The various subclasses may be delineated briefly as follows. Dwarf novae are cataclysmic variables undergoing sudden increases in their visual brightness, by 2–5 magnitudes approximately, for a period of a few days up to more than a week, after which the visual brightness returns to the quiescent level. Systems showing outbursts of extra magnitude and length ('superoutbursts') in addition to their ordinary outbursts are called SU UMa dwarf novae, and those in which the brightness may linger for long periods at intermediate levels before returning to quiescence are called Z Cam systems. Dwarf novae that only undergo ordinary outbursts are called U Gem systems. Cataclysmic variables in which a strong magnetic field of the white dwarf locks the white dwarf in corotation with the orbit are called AM Her systems; those in which the white dwarf has a strong magnetic field that does not lock its rotation to the orbit are called DQ Her systems. Cataclysmic variables that spend

Figure 1. The period distributions of the various subclasses of cataclysmic variables, according to the compilation of Ritter & Kolb (1995). Shown (in ascending order) are unclassified dwarf novae, systems named after their prototypes U Gem, Z Cam, SU UMa, AM Her, DQ Her, UX UMa and VY Scl, old novae known to undergo dwarf nova outbursts and other old novae. Systems with a white-dwarf or subgiant donor are omitted.
most of their time at a relatively bright level, but occasionally decline to low brightness levels for extended periods of time, are called VY Scl systems. The remaining cataclysmic variables, which are permanently bright, I will refer to as UX UMa systems. Cataclysmic variables of all these classes may undergo nova outbursts, and old novae are also shown in Fig. 1, where I separate those that have shown dwarf nova outbursts from those that have not. Details on these subclasses and their properties may be found in the monograph by Warner (1995). With respect to the table as given by Ritter & Kolb (1995), one change has been made in that 1H 1752 + 081 is now known to be an AM Her type system; and two points of uncertainty are that FY Per, listed in the catalogue as a possible nova-like variable and shown in the figure as a UX UMa system, may not be a cataclysmic variable (Okazaki 1993), whereas Nova Vir 1929, shown in the figure with the novae that are also dwarf novae, may not have been a nova (Ritter, private communication). These uncertainties may mean that there are neither novae that are also dwarf novae nor UX UMa systems below the period gap; they do not affect any of the following discussion.

It has been noted before that the period distributions of various subclasses differ from the overall period distribution of all cataclysmic variables. In particular, SU UMa and AM Her systems occur mainly, if not exclusively, below the period gap (i.e. at periods shorter than 2 h), and U Gem, Z Cam and DO Her systems mainly above the period gap. A problem in interpreting the observed period distribution arises from strong selection effects in the discovery of cataclysmic variables. In particular, many of the AM Her and DO Her systems, but very few of the other subclasses, are detected first as X-ray sources, and only subsequently identified with cataclysmic variables. The VY Scl systems are limited to the range just above the period gap, and this has led to the suggestion that these systems are UX UMa type systems in which the mass transfer is beginning to switch off, before they enter the period gap (Robinson et al. 1981). I will suggest below that another interpretation is also possible, in which VY Scl systems are dwarf novae that switch on for extended periods.

2 THE PERIOD DISTRIBUTION ABOVE THE PERIOD GAP

Let us look first at the distribution of periods above the period gap, more specifically, at periods above 2.5 h. Fig. 2 shows the period distributions of all dwarf novae and of the nova-like variables, i.e. the remaining cataclysmic variables. Old novae that undergo dwarf nova outbursts are classed with the dwarf novae. In agreement with the usual assumption (see e.g. Warner 1995), we class the VY Scl systems with the nova-like variables. The cumulative distributions are also shown in Fig. 2, and are clearly different: the nova-like variables are more frequent close to the period gap than are dwarf novae. The probability that the dwarf nova-period distribution is drawn from the same parent population as the period distribution of the nova-like variables is slightly less than 1 per cent, according to a two-sided Kolmogorov–Smirnov test (for which see Press et al. 1992, chapter 14). This difference between the two distributions has already been noted and discussed in terms of the disc instability model by Shafter (1992).

3 THE OVERALL PERIOD DISTRIBUTIONS

Fig. 4 shows the period distributions of the dwarf novae (including the VY Scl systems) and of the nova-like variables for the full period range of Fig. 1. The two distributions are significantly different, and would have been more different if we had included the VY Scl systems with the nova-like variables. Perhaps the most striking feature in Fig. 4 is that the period gap is no longer very evident in the distribution of nova-like variables. This may be quantified as follows: the probability that the period distribution of the nova-like variable is compatible with a broken straight line
Period distributions of cataclysmic variables

42 dwarf novae, 58 nova-likes

\[ \log P_{ks} = -0.4 \]

Figure 3. As Fig. 2, but now with the VY Scl systems classed with the dwarf novae. The distributions are the same within the statistical uncertainty.

81 dwarf novae, 86 nova-likes

\[ \log P_{ks} = -1.8 \]

Figure 4. The period distributions of the dwarf novae (including VY Scl systems) and of the nova-like variables of Fig. 1. The dashed line shows the cumulative distributions of the dwarf novae, the solid line that of the nova-like variables. The two distributions are significantly different, at the level indicated in the figure, according to a two-sided Kolmogorov-Smirnov test. In the distribution of the nova-like variables only, the period gap is not significant.

\[ N(<\log P_b)/N = 1.15(\log P_b - 0.1) \text{ for } \log P_b \leq 0.875 \text{ and } N(<\log P_b)/N = 0.63 + 0.31 \log P_b \text{ for } \log P_b > 0.875 \]

is about 45 per cent, according to a one-sided Kolmogorov-Smirnov test (for which see Press et al. 1992). Here \( P_b \) is in hours. Thus a turnover in the cumulative distribution of the nova-like variables at the high end of the period range is required, but the dearth of systems in the period gap around 2.5 h is not significant. For the dwarf novae, on the other hand, the period gap still is significant.

4 DISCUSSION

4.1 The VY Scl phenomenon and dwarf nova outburst models

On the basis of the period distributions in Fig. 1 it would appear that the VY Scl phenomenon, in which cataclysmic variables that are usually bright show extended intervals of lower luminosity, could be considered as a variant of the dwarf nova phenomenon. From the purely phenomenological point of view, it seems to me that classification of the VY Scl systems with the dwarf novae makes eminent sense, as this brings together all cataclysmic variables which undergo large brightness variations repeatedly. Indeed, the long-term lightcurve of, for example, MV Lyr between JD 2444500 and 2447500 (Warner 1995, p. 244) looks similar to those of dwarf novae. It should be noted that the long-term lightcurves of many cataclysmic variables are not well known, so that the above statement is subjective. Where Z Cam systems show very long periods of sustained brightness at a level intermediate between minimum and maximum, the VY Scl systems may be considered as more extreme, in the sense that they spend extended periods at the maximum level.

It is agreed that dwarf nova outbursts correspond to increased accretion on to the white dwarf, but whether the cause of this lies in increased mass transfer from the donor star or in a mass-flow instability inside the accretion disc is less clear. Theoretical work in recent years has concentrated on the disc instability, but problems with this model remain, even as more model features are added (e.g. Verbunt 1991; for a more positive view see Cannizzo 1993). For example, extended maxima are difficult to explain in these models, which predict immediate onset of the flux decline once maximum is reached. This problem would be exacerbated if the VY Scl phenomenon were, as we suggest, a variant of the dwarf nova phenomenon, to be explained within the framework of the same model.

It is an interesting puzzle that the VY Scl phenomenon is limited to a narrow period range just above 3 h; remarkably, AM Her, the prototype of another subclass of the cataclysmic variables, and with an orbital period also in this range, shows long-term variation not dissimilar to those of the VY Scl systems (see the lightcurve in Feigelson, Dexter & Liller 1978). In the absence of an accretion disc in AM Her, its long-term variations can only be the result of variations in mass transfer from the donor; by extension via the VY Scl systems to the dwarf novae, this suggests that variations in mass transfer from the donor play an important role in dwarf nova outbursts as well.

4.2 The period gap and low-mass binary evolution

It would be premature to say that the period gap has disappeared, but in my view the period distributions of Fig. 1 raise serious doubts about its interpretation. The observed gap is statistically significant for the dwarf novae (Fig. 4),
and for the period distribution of the purely magnetic systems, i.e. the AM Her and DQ Her systems combined (see Wheatley 1995; the larger number of AM Her systems in that paper is due mainly to systems with uncertain periods or uncertain classifications). In Fig. 1 it may be seen that the systems filling the period gap for the nova-like variables are mainly UX UMa systems and old novae.

The doubt arises from the fact that the systems below the gap are of different subclasses than those above the gap: the vast majority of systems below the gap are either AM Her or SU UMa systems. Since different subclasses are discovered in very different ways (e.g. magnetic systems by their strong X-ray fluxes, dwarf novae by their outbursts or their strong emission lines in the quiescent state), they are also subject to very different selection effects. The limitation of subclasses to well-defined period ranges – with the VY Scl phenomenon as the most pronounced example – means that the absence of discovered systems in a particular period range may well be a result of the absence of easily identifiable phenomena in that period range, rather than to the absence of cataclysmic variables. If phenomena that increase the detection probability of a cataclysmic variable are concentrated at particular period ranges, an apparent dearth of observed systems could arise in the region between. Looking at Fig. 1 we could suggest, for example, that the observed period gap is due to the concentration of AM Her and SU UMa systems towards short periods, and of UX UMa, U Gem and Z Cam systems to longer periods. It would seem therefore that a better understanding of the relation between the various subclasses of cataclysmic variables is required before we can pronounce confidently on the meaning of the dearth of observed systems in the 2–3 h period range. For example, do U Gem and Z Cam systems turn into VY Scl systems when their evolution brings them near the 3 h period range? Do VY Scl systems turn into nova-like variables at 3 h?

If the period gap indeed does not exist in the intrinsic period distribution of all cataclysmic variables (as opposed to the observed distribution affected by period-dependent selection effects), then we may discard models designed to explain the period gap, such as the interrupted magnetic braking model (Spruit & Ritter 1983; Rappaport, Joss & Verbunt 1983). Conclusions drawn about the strength of magnetic braking above the period gap on the basis of the width of the gap would also be invalidated, and therefore it would no longer be obvious how important magnetic braking actually is for the long-term evolution of cataclysmic variables. By analogy, the importance of magnetic braking for low-mass X-ray binaries – which incidentally also show no period gap – would be in doubt as well. The original incentive for the introduction of strong magnetic braking was the required explanation for mass-transfer rates higher than can be explained with loss of angular momentum from gravitational radiation (Verbunt & Zwaan 1981). As many systems show large variations in brightness levels, it is not obvious how much their mass transfer rates, averaged over long ( > 10^7 yr, say) intervals, are in excess of the prediction from gravitational radiation.

REFERENCES


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