

Dwarf Nova Oscillations and Quasi-Periodic Oscillations: Extension of the Two-QPO Diagram of X-Ray Binaries, and a new kind of DNO

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Abstract. Seventeen examples are given of Cataclysmic Variable (CV) stars possessing both Dwarf Nova Oscillations (DNOs) and Quasi-Periodic Oscillations (QPOs). These form an extension of the X-Ray Two-QPO correlation to frequencies three orders of magnitude lower. We draw attention to the existence of a second type of DNO in CVs, which is probably caused by magnetically channelled accretion onto the white dwarf.

1. Introduction

We reported at the August 2001 Göttingen meeting on CVs that VW Hyi in outburst has Dwarf Nova Oscillations (DNOs) and Quasi-Periodic Oscillations (QPOs) that keep an approximately constant period ratio of ~ 16 as they vary in period by a factor of two during the late stages of outburst (Warner & Woudt 2002a; see also Woudt & Warner 2002). Interpreting the DNOs and QPOs in VW Hyi as analogues of the high and low frequency QPOs observed in X-Ray binaries, we showed that VW Hyi lies on an extension to low frequencies of the two-QPO correlation in X-Ray binaries found by Psaltis, Belloni & van der Klis (1999). An important addition to this correlation was made by Mauche (2002), who found that the X-Ray DNOs and QPOs in SS Cyg also fall on this relationship, which helps to close the gap between the CVs and the X-Ray binaries.

One aspect of QPOs in CVs is that double DNOs are sometimes observed, and their frequency difference is equal to the QPO frequency (Woudt & Warner 2002) - which we interpret as the DNO rotating beam reprocessed off a progradely travelling wave in the inner disc (Warner & Woudt 2002b). Therefore, even if a QPO is not directly observed in a light curve, a proxy for it can be found when double DNOs are observed.

2. The Two-QPO Diagram for CVs and X-Ray Binaries

Armed with this knowledge we have searched the literature for examples of the simultaneous appearance of DNOs and QPOs, or their proxies. Table 1 lists the results of the search.

Table 1. DNOs and QPOs in CVs (periods in seconds).

Star	DNOs	QPOs	References
V3885 Sgr	29.08 30.1	[819]	Hesser, Lasker & Osmer 1974
WZ Sge	27.87 28.95	742	Warner & Woudt 2002b
SS Cyg	7.7	83	Mauche 2002
V436 Cen	19.6	475	Warner & Woudt 2002b
	19.45 20.29	[470]	Warner & Woudt (unpublished)
V2051 Oph	28.06 29.77	[489]	Steeghs et al. 2001
UX UMa	29	650	Nather & Robinson 1974
IX Vel	~ 28	~ 500	Warner et al. 1985 Williams & Hiltner 1984
TY PsA	27	245	Warner et al. 1989
GK Per	351	~ 5000	Morales-Rueda et al. 1996, 1999
RX And	35.7	~ 1200	Szkody 1976
SW UMa	22.3	~ 300	Robinson et al. 1987
RU Peg	2.94?	50	Patterson et al. 1977

Notes: values in square brackets are deduced from double DNOs. In RU Peg the observed DNO period is 11.1 s, which is probably a beat with the integration duration.

In addition, we have four CVs in which we have recently observed DNOs and QPOs; these are listed in Table 2.

Table 2. Newly observed DNOs and QPOs (periods in seconds).

Star	Type	DNOs	QPOs
WX Hyi	Dwarf Nova	12.1	190
VZ Pyx	Dwarf Nova	23.86	390.5
EC 2117-54	Nova-like	22.11 23.28	470
HX Peg	Dwarf Nova	112.28	1800

The addition of these data, obtained from observing the literature and observing the sky, to the Two-QPO diagram produces the correlation shown in Figure 1. It can be seen that the CV DNO and QPO observations lie on an

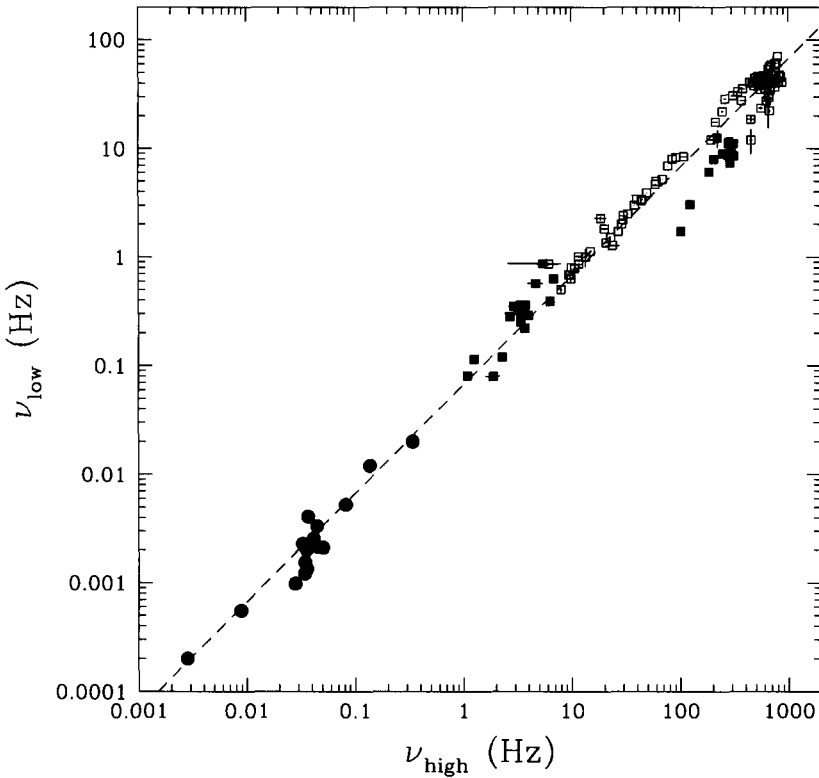


Figure 1. The Two-QPO diagram for X-Ray Binaries (filled squares: black hole binaries; open squares: neutron star binaries) and 17 CVs (filled circles). The X-Ray binary data are from Belloni, Psaltis & van der Klis (2002) and were kindly provided by T. Belloni. The dashed line marks $P_{QPO}/P_{DNO} = 15$.

extension of the X-Ray Binary relationship to frequencies nearly three orders of magnitude lower. The essence of both the CV and the X-Ray correlations is that $P_{QPO} \sim 15 P_{DNO}$.

Adopting a magnetically controlled accretion model for DNOs (Paczynski 1978; Warner 1995; Warner & Woudt 2002b), the DNO period is clearly related to the Keplerian period at the magnetically truncated inner edge of the disc. A number of recent papers modelling accretion into magnetospheres find quasi-periodic accretion or oscillations (e.g. Uzdensky 2002; Titarchuk & Wood 2002); a quantitative model by Goodson, Bohm & Winglee (1999) deduces $P_{QPO}/P_{DNO} \sim 100/2\pi \sim 16$.

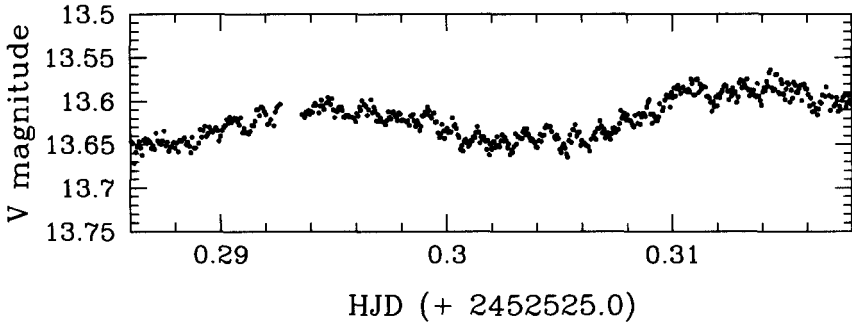


Figure 2. Longer period DNOs observed in EC 2117-54

3. A New kind of DNO

During the literature search for DNOs and QPOs we noticed that there are occasionally additional DNOs listed that do not fall into the above category - indeed, several CVs show two sets of DNOs simultaneously. Furthermore, the second kind of DNOs behave very differently from the 'classical' DNOs, in that their periods are relatively independent of outburst state, and they can appear during quiescence of dwarf novae (which, apart from the apparently more strongly magnetic systems WZ Sge and GK Per, normal DNOs do not).

The new type of DNOs, which we will refer temporarily as 'longer period DNOs' - lpDNOs, are demonstrated in the following stars:

VW Hyi: In a superoutburst of VW Hyi observed in 1975 Haefner, Schoembs & Vogt (1977, 1979, see also Schoembs 1977) found an ~ 80 s DNO which persisted for nine nights and changed only slightly and erratically in period although the star decreased in brightness from mag 10.6 to 13.7. We have also seen occasional DNOs near 88 s in VW Hyi. The normal DNO periods in VW Hyi range from 14 s at maximum of outburst to 40 s near return to quiescence (Woudt & Warner 2002).

EC 2117-54: This newly discovered nova-like CV, from the Edinburgh-Cape Survey, possesses normal (including double) DNOs near 23 s and QPOs near 450 s, but in addition frequently shows lpDNOs near 94 s (see Figure 2). Thus EC 2117-54 has a suite of oscillations that closely resembles that of VW Hyi in outburst.

SS Cyg: Robinson & Nather (1979) and Patterson (1981) observed what they described as QPOs in the range 32 – 36 s in two different outbursts of SS Cyg, at the same time ~ 10 s normal DNOs were present.

HT Cas and AH Her: Patterson (1981) observed ~ 100 s QPOs in HT Cas and AH Her in outburst, where the normal DNOs are ~ 20 s and ~ 25 s respectively. The HT Cas oscillations were also often seen during quiescence.

OY Car: We have observed strong ~ 50 s oscillations during one observational run on OY Car at quiescence. This star has normal DNOs of 18 – 28 s during outbursts.

For a possible interpretation of the lpDNOs we turn to measurements of $v \sin i$ of the white dwarf primaries. In VW Hyi Sion et al. (1996, 2001) have found projected rotational velocities in the range 300 – 500 km s⁻¹. For $i = 65^\circ$ and a primary mass of 0.6 M_\odot this gives a rotation period of 120 – 165 s. The observed lpDNO may therefore be associated with the bulk rotation of the primary (as opposed to the rotation of the equatorial belt in the case of the normal DNOs - Warner & Woudt 2002a,b), with two-pole magnetic accretion. A similar result is obtained for SS Cyg, with $v \sin i = 300$ km s⁻¹ (Sion 1999), $i = 50^\circ$ and $M = 1.2 M_\odot$, which give a primary rotation period ~ 63 s.

We suggest, therefore, that the lpDNOs result from accretion controlled by the magnetic field of the primary itself, whereas the normal DNOs come from accretion onto the equatorial belt where a stronger field is generated by differential rotation.

Acknowledgments. BW is supported by funds from the University of Cape Town; PAW is supported by strategic funds made available to BW by the University of Cape Town and by the National Research Foundation. We thank T. Belloni for kindly providing us with the X-Ray Binary data shown in Figure 1.

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