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Simulations of disk precession in CVs

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Abstract. In this work, we review disk precession in Cataclysmic Variable systems. Although retrograde and prograde precession has long been associated with negative and positive superhump photometric modulations, respectively, the sources to the superhumps and the precessions have not yet reached consensus. Smoothed Particle Hydrodynamic (SPH) simulations suggest that the negative superhump fundamental frequency is due to a disk tilt around the line of nodes, and that retrograde precession is due to a net tidal torque on the tilted, differentially rotating, elliptical disk. To learn more about the positive superhump and prograde precession, we isolate the fundamental positive superhump frequency. SPH simulations confirm the largest change is disk shape from circular (near superhump minimum) to highly eccentric (near superhump maximum) to circular within one positive superhump period. Two dense waves are within the disk near superhump minimum and along the rim near superhump maximum. The dense waves cyclically dissipate and form but do not appear to advance as suggested by others. Advancing density waves are likely the signatures of harmonic(s).

Key words. Stars: abundances – Stars: cataclysmic variables – Methods: Numerical – Hydrodynamics – Accretion, accretion disks – Waves

1. Introduction

Cataclysmic Variables (CVs) are close binary systems that contain a white dwarf primary accreting material from a low-mass main-sequence secondary. CVs are photometrically active, exhibiting variability on timescales of seconds to centuries (e.g., Warner 1995). The dwarf novae (DN) subclass of CVs experience quasi-periodic outbursts of a few magnitudes. The source to outbursts is thought to be a thermal instability: Mass accumulates in a disk until a critical surface density is reached, transitioning the local disk fluid from a low-viscosity state to a high-viscosity state. This high-viscosity state propagates inward and/or outward until the entire disk is in the high state, transporting both angular momentum and mass (see e.g., Lasota 2001). In addition to normal outbursts, CV DN SU UMa systems experience superoutbursts that last a few times longer and are up to a magnitude brighter than the outbursts. The source to superoutbursts is thought to be a tidal instability: The disk expands outward until the m=3 eccentric inner Lindblad resonance radius is reached. After enough disk mass has expanded beyond this radius, the disk is tidally forced into changing shape.

A characteristic of SU UMa systems is periodic, large-amplitude, photometric modulations having a period that is a few percent

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Send offprint requests to: M.M. Montgomery longer than the orbital period. These positive superhumps are also seen in novalike (NL) CVs (e.g., Patterson et al. 1993), AM CVn systems (e.g., Patterson et al. 1993), and in low-mass X-ray binaries (e.g., Mineshige 1992). NLs have a nearly constant luminosity, suggesting that positive superhumps are not intrinsically tied to superoutbursts. In addition to positive superhumps, negative superhumps are also sometimes found in SU UMa systems. These superhumps have a period that is a few percent shorter than the orbital period, and are also seen in NLs (e.g., Skillman et al. 1998), AM CVn systems (Skillman et al. 1999), and in low-mass X-ray binaries (e.g., Retter 2002). Sometimes negative and positive superhumps appear simultaneously (e.g., Harvey et al. 1995).

Systems that show positive or negative superhumps in their light curves also sometimes show signatures of a progradely or retrogradely precessing disk. Some systems simultaneously show both superhumps as well as both precessions (e.g., Skillman et al. 1999), suggesting that superhumps are linked to precession. In this work, we review disk precession and superhumps in CV systems.

2. Prograde precession and positive superhumps

To obtain prograde precession and positive superhumps, the disk needs to expand outward beyond the m=3 eccentric inner Lindblad resonance radius. For SU UMa systems, a few to several repeat outbursts are needed, the repetition of which increases the disk radius. After enough mass is located beyond the critical radius, the disk can be tidally forced into changing shape and into prograde precession (see e.g., Whitehurst 1988, 1994; Simpson & Wood 1998). The time to cycle the disk's shape is one positive superhump period.

Although the positive superhump is known to be from viscous dissipation during one positive superhump period, the source to the dissipation within the disk has not yet reached consensus. As suggested in Wood et al. (2011), the positive superhump's source is a compression of the disk on the far side, the side opposite the secondary. We test this hypothesis by running a similar simulation using the same base SPH code as described in Simpson & Wood (1998) and Montgomery (2009). We model the SU UMa SDSS J162520.29+120308.7 that has a possible orbital period P_{orb}=0.09111(15) days and a 4.6% longer, stable positive superhump period P_{+}=0.09531(5) days (Olech et al. 2011). We assume a white dwarf primary mass M_1=0.82$M_{\odot}$, a primary-to-secondary mass ratio q=0.24, and we simulate with standard viscosity coefficients and with 25,000 particles.

In Figure 1, we plot artificial light curves and Fourier transform for the simulation of SDSS J162520.29+120308.7. Approximately one slight positive superhump modulation ~7.5% longer than P_{orb} is produced per orbit. As shown, the fundamental has been isolated. The procedure used to create figures like these is discussed in Montgomery (2012).

In Figure 2, we show snapshots near positive superhump minimum and maximum. As shown, dense waves are present interior to the disk near superhump minimum and along the disk rim near superhump maximum. The largest change is disk shape during one positive superhump period. The excess viscous dissipation seems to be the growth and decay of the more dense waves along the rim (a similar result is shown in Whitehurst 1988, 1994). The source to the density waves is tidal torquing of the disk material that has expanded beyond the 3:1 resonance radius: The secondary gravitationally pulls more on the near side than the far side, changing the disk's moment of inertia and shape. From superhump minimum to maximum, the disk rim moves into the inner density wave on the far side while the inner density wave moves into the disk rim on the near side. The formation and dissipation of the two waves and the compressions are cyclic. The time the disk takes to cyclically change shape is slightly longer than the orbital period: The secondary needs to advance a bit further than one orbital period to meet up with the next cycle of changing disk shape.

In this simulation (and in Whitehurst 1988, 1994), we do not see advancing waves. As the simulations in Simpson & Wood (1998) show both the fundamental and harmonic(s), the advancing waves are likely the sources to the harmonic(s).

3. Negative superhumps and retrograde precession

To obtain retrograde precession and negative superhumps, numerical simulations show an SU UMa disk eventually tilts and retrogradely precesses (Montgomery 2012). Because only the fundamental negative superhump frequency is induced as well as the disk tilt in the simulation and because no fundamental is seen when the disk is in the orbital plane, disk tilt and the negative superhump fundamental frequency must be intrinsically linked. The disk needs to be tilted more than three degrees for a fundamental frequency to be three sigma or more above the noise (Montgomery 2009).

As the only unknown in the code is the Shakura & Sunyaev (1973) α viscosity and the numerical code neither includes magnetic fields nor central radiation sources, the source to disk tilt cannot be due to effects by magnetic fields or by central radiation sources. Because the primary, secondary, and disk are in alignment, gravitational force is also not a likely candidate. One potential source to tilt is the lift force (Montgomery & Martin 2010) as basic ingredients are minimum mass transfer mass, disk mass, and disk radius, ingredients common to many accreting systems. The lift force is not restricted to a particular disk radius to generate negative superhumps, unlike the generation of positive superhumps.

Once the disk is tilted, the net tidal torque by the secondary on the tilted, spinning, elliptical disk can cause the disk to retrogradely precess Montgomery (2000b). This retrograde precession is numerically shown in Montgomery (2012). In the simulation, the gas stream strikes the tilted disk rim and flows over the disk for roughly one-half of an orbital period followed by flow under the disk rim for approximately the other half orbital period. The location on the disk rim where the gas stream flows over or under the the disk retrogradely precesses like the retrograde precession of the First Point of Aries, where the ecliptic and the celestial sphere cross (Montgomery 2000b).

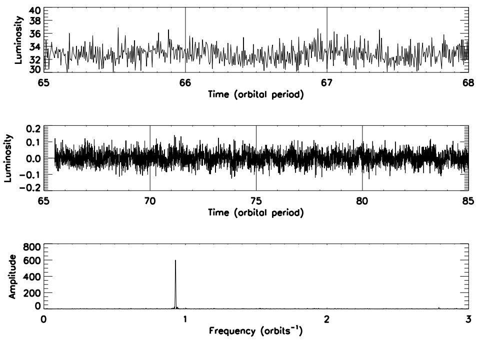

Fig. 1. Artificial bolometric luminosity from the simulation of SDSS J162520.29+120308.7 for orbital periods 65.0 to 68.0 (top panel, unsmoothed) and 65.0-85.0 (middle panel, smoothed). The Fourier Transform of orbits 65-235 (lower panel) shows the fundamental positive superhump frequency ν_{+}=0.9298orbit^{-1} where one orbit is P_{orb}.

In Figure 3, we plot artificial light curves and Fourier Transform for the simulation discussed in Montgomery (2012). Two negative superhump modulations are produced per orbit, each one occurring while the gas stream overflows the disk rim and impacts each disk face. As disks are optically thick, an observer would only see approximately one modulation per orbital period. As shown in the top panel of Figure 3, the negative superhump signal is not well about the noise which means that this disk is not tilted above three degrees.

4. Conclusions

In this work, we review sources to precession and superhumps in non-magnetic CVs. Positive superhumps and prograde precession are simulated to occur when the disk is tidally forced into changing shape. Negative superhumps and retrograde precession are simulated to occur when the disk tilts around the line of nodes.

In a future paper, we discuss changes to the disk when the harmonics to the positive and/or negative superhump fundamental frequencies are present, and we further explain the precession of the disk.

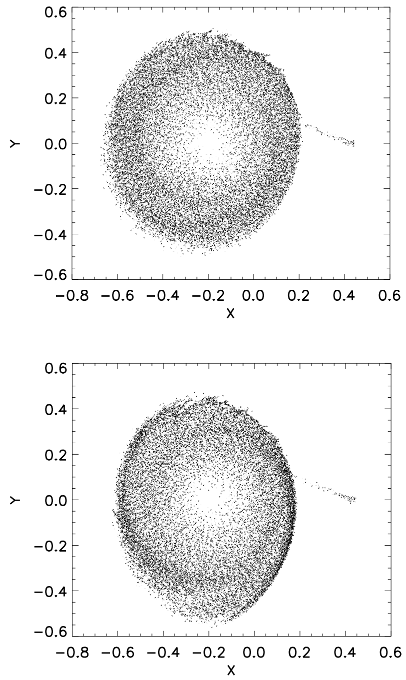

Fig. 2. Face-on snapshots of the disk near positive superhump minimum (top panel, orbit 65) and near positive superhump maximum (bottom panel, orbit 75) for the simulation described in Figure 1.

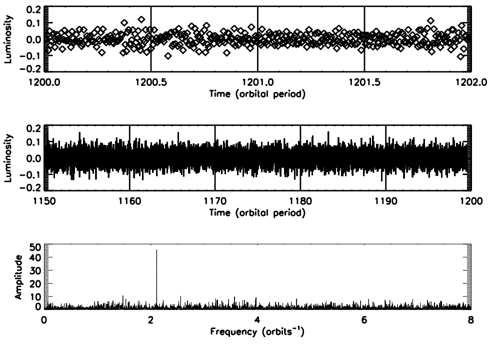

Fig. 3. Artificial bolometric luminosity from q = 0.45 simulation with M_1=0.6$M_\odot$ for orbital periods 1200 to 1202 (top panel, smoothed) and 1150-1200 (middle panel, smoothed). The Fourier Transform of orbits 700-1200 (lower panel) shows the fundamental negative superhump frequency. The frequency is $2\nu_{-}$=2.097orbit^{-1} where one orbit is P_{orb}.

5. Discussion

PAULA SZKODY: This is the same flow that has been postulated for SW Sex stars, but they do not show any evidence of positive or negative superhumps. Why not?

MICHELE M. MONTGOMERY: The disk may not significantly tilt to produce observable negative superhumps. We do not yet know why positive superhumps are not observed.

PABLO RODRIGUEZ-GIL: Do you think the magnetic pressure of the white dwarf's magnetic filed is a plausible and effective way of tilted the disc in the SW Sex stars?

MICHELE M. MONTGOMERY: My colleagues are working on this topic. We only present sources common to all types of systems in this work. We will have to wait for their (and other) forthcoming paper

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