Ca II spectroscopic survey of short orbital period CVs

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Accreting binaries containing white dwarfs provide crucial benchmark populations for stellar and binary evolution models and are thought to be the progenitors of Type 1A super novae explosions. The determination of the system parameters has been proven difficult as these systems are few and faint. Using the previously ignored CaII emission lines in the I-Band we are probing new diagnostic tools in the search for system parameters of low mass ratio systems.

Introduction

Cataclysmic Variables (CVs) are binary star systems containing a white dwarf (WD) and a low mass main sequence secondary star. The secondary star will lose mass towards the WD via Roche Lobe Over Flow, which will form an accretion disc around the WD. Outbursts of these discs can brighten the system by factors of several thousands. Those systems that have a very short orbital period and show only very rare super-outbursts are called WZ Sge type Dwarf Novae.

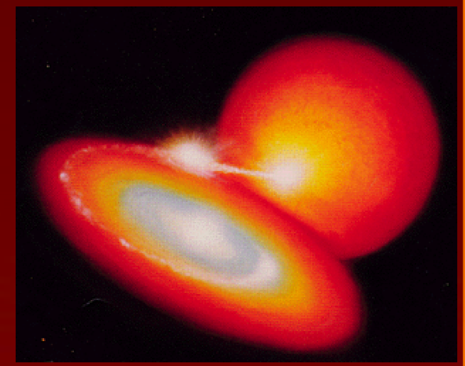


Figure 1: Artist impression of a CV from www.nasa.gov

Background

Evolutionary studies predict the majority of the binary systems to have evolved towards short periods (1 - 2 hours) but only a few have been found and even fewer have determined system parameters other then their period. The lack of resolved component masses in this regime currently prevents the verification of CV evolution in detail.

To estimate the binary parameters, indirect methods are mostly being used, such as the empirical correlation between the binary mass ratio q (=M_2/M_1) and the precession period of the accretion disc when q is sufficiently small (Figure 2). These discs can show photometric modulations on periods slightly longer than their orbital periods and the relative excess between this so-called superhump period and orbital period is potentially a simple function of the binary mass ratio (Patterson, 2005). The low mass side is still very much reliant on the badly determined mass ratio of WZ Sge and any precise mass determination of a short orbital period system will greatly improve the fit. Potential candidates have been identified by Knigge (2006) and Patterson (2009).

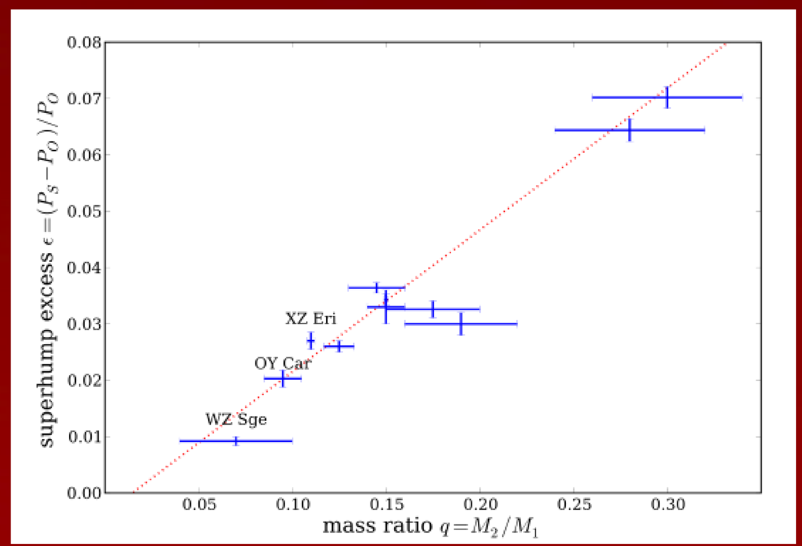


Figure 2: Mass ratio versus superhump period with empirical relation by Patterson (2005)

Method: Doppler tomography

During quiescence the disc contains optically thin emission regions that power strong and broad emission lines. According to the Doppler effect, these lines will shift relative to their rest-wavelength as the system rotates around its centre of mass. Obtaining spectra during different phases of the orbit allows us to make a velocity-velocity map of the system. The different components (disc, WD, secondary and stream) all project to unique positions on the Doppler map (see Figure 3) giving us an indirect tool to measure their projected radial velocities K_{disc}, K_1 and K_2 and the location of the stream impact point on the disc. The period, the mass ratio q (= K_1/K_2) and an independent measurement of either M_1 or M_2 then solves all the system parameters.

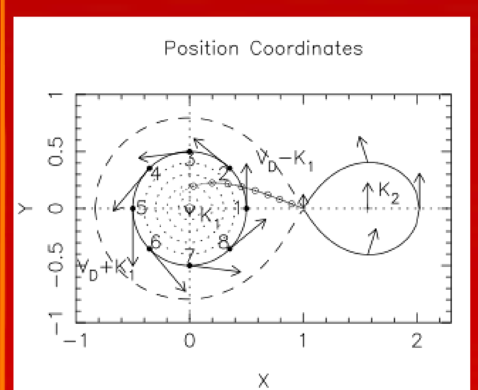
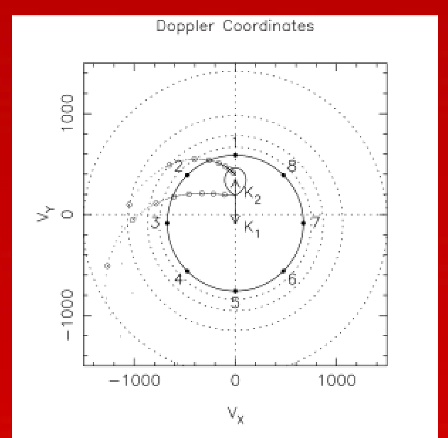


Figure 3: Projection from position coordinates to velocity coordinates. The left figure is a binary system viewed from above in a rotating frame, containing the WD, the secondary filling its Roche Lobe, the stream and a disc. Arrows represent the velocity of the components. The right figure shows the projection of the same components into a velocity - velocity plane. The WD projects at -K_1, the secondary at +K_2. The Keplerian disc is projected inwards out as the outer disc has the smallest velocity. Figures provided by Keith Horne.



Prototype: GW Lib

GW Lib is the first multi-period non-radial pulsating WD found in an accreting binary and with a period of 76.79 min (Thorstensen et al, 2002) very close to the period minimum which implies an evolved binary. Several studies have failed so far, to resolve the system parameters. However it must have a very low inclination of 11° (Thorstensen et al, 2002) and a WD mass of 0.8-1.0 M☉ (Szkody et al, 2002, Townsley 2004, respectively).

In July 2007 we obtained time resolved spectra for GW Lib with the William Herschel Telescope on La Palma. The setup covered both the commonly used Balmer range as well as the CaII triplet around 860nm. Figure 4 shows both the Hβ λ486.1nm and the CaII λ866.2nm Doppler maps and reveals the secondary star for the first time, see van Spaandonk et al, 2009.

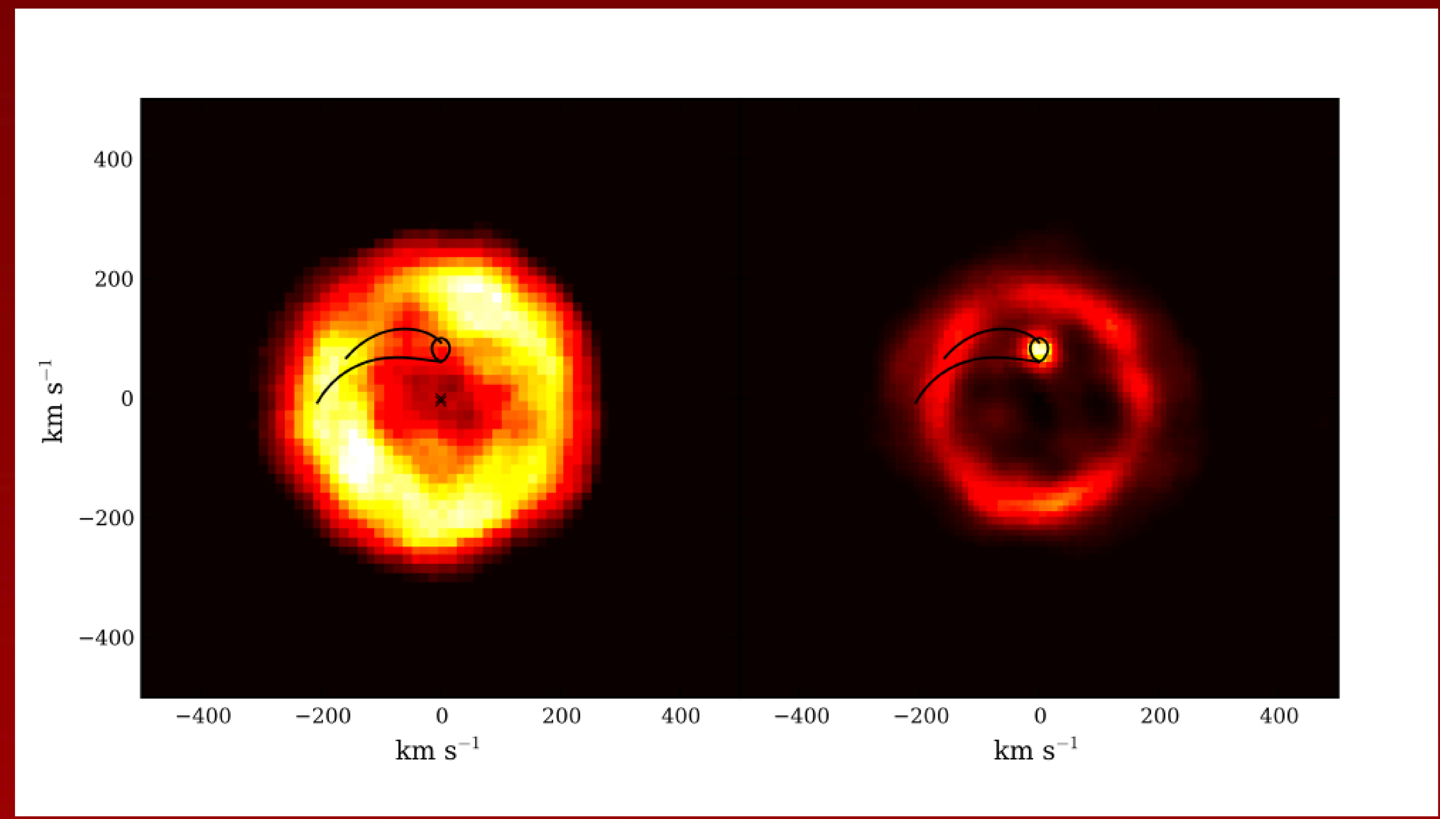


Figure 4: Doppler maps of GW Lib on 24th of July 2007. Left is the Hβ map, right the CaII map. Where the Balmer map shows a diffuse ring of emission from the accretion disc, the CaII maps shows a much better defined ring with significant asymmetry and the secondary star manifests itself as a sharp emission spot with a radial velocity of ~85 km s^{-1}.

WD mass determination in GW Lib:

Previously gathered spectra obtained with a very high resolution spectrograph at the VLT in Chili, showed magnesium in absorption. As this line originates from near the WD surface, it is red-shifted due to the WDs gravitational field. This line can only be visible in systems with a very low accretion rate. Via $V_{grav}=GM_{WD}/cR_{WD}$ and several Mass-Radius relations for WDs, this provides us with a direct measurement of the WD mass at 0.85±0.05M☉, see Figure 5.

Table 1 lists the now resolved system parameters for GW Lib where q is derived from the measured superhump (Kato, 2008) and a K-correction is applied to K_2 as the emission only originates from the irradiated side of the secondary.

Table 1: System parameters

q	=	0.062
M_1	=	$0.85\,M_\odot$
M_2	=	$0.05\,M_\odot$
K_2	=	$100.8\,\mathrm{km\,s^{-1}}$
K_1	=	$6.3\,\mathrm{km\,s^{-1}}$
v_1	=	$32\,\mathrm{km\,s^{-1}}$
v_2	=	$509\,\mathrm{km\,s^{-1}}$
i	=	11.4

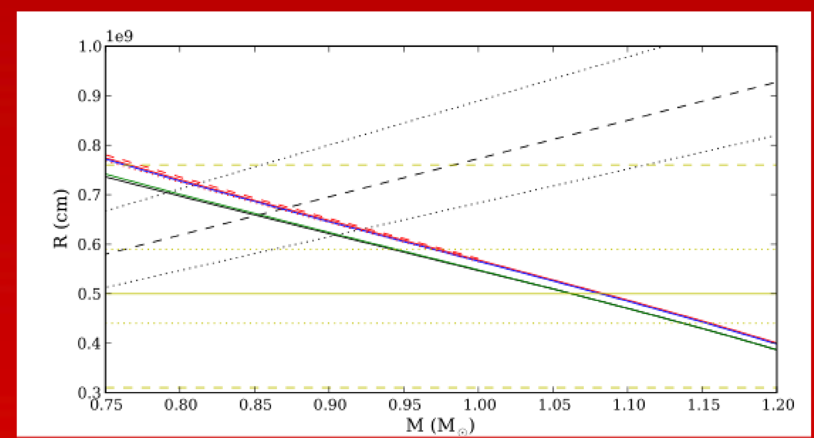


Figure 5: The black dashed line is the measured gravitational redshift of the MgII line at λ448.1nm as a function of mass and radius of the WD ($V_{grav}=GM_{WD}/cR_{WD}$) with a 3σ error (dotted black lines). Several mass-radius models for WDs change the mass of the WD in GW Lib by not more than 5% (zero - T: solid black; non-zero T and pure C-core: red; CO core with H layer: Blue; CO core with no H layer: green. The solid yellow horizontal line gives the radius of the WD calculated from the UV-flux combined with a distance of 100pc (Szkody et al, 2002, Thorstensen, private communication) together with 1σ error (yellow dotted) and 3σ error (yellow dashed) lines.

Survey Results

As part of our survey we have acquired time resolved spectroscopy covering the I-band of several potential low mass-ratio systems with a measured superhump period. The average profiles can be found in Figure 6, where figure 7 gives two example Doppler maps. Out of these 8 systems, 3 have a confirmed secondary star in the Doppler maps, 2 have a possible secondary but we lack S/N and resolution to confirm this. One system can not form a disc as the WD is highly magnetic, hence doesn't exhibit superhumps. However the CaII lines are still strong and give a better confined location of the secondary star. The final 2 systems show no sign of a secondary star as the CaII lines are strongly contaminated by the nearby Paschen lines.

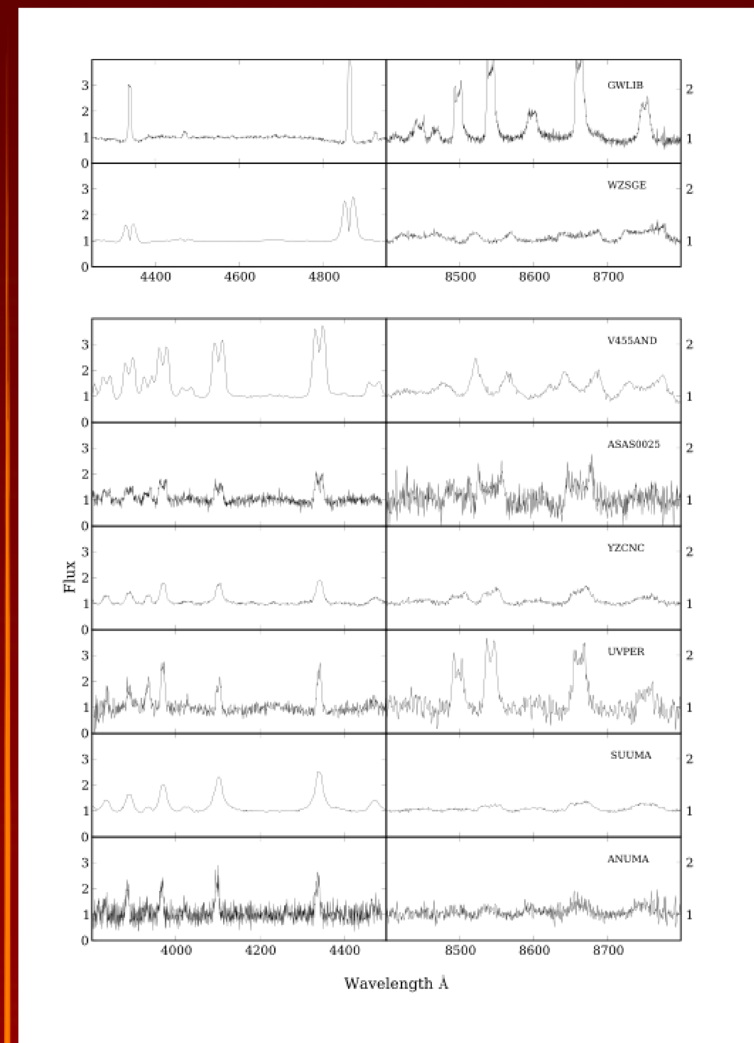
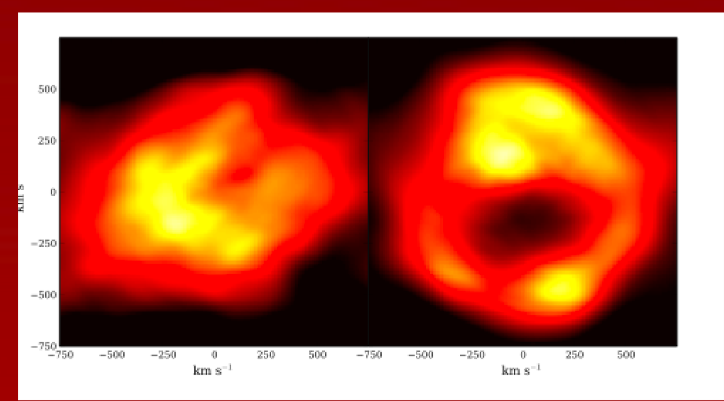


Figure 6: Average spectra. Left hand side shows the blue wavelength range and the right hand side the red wavelength range. Systems with positively detected secondary star are: GW Lib, SU Uma and YZ Cnc. Possible secondary stars are present in ASAS 0025 and UV Per. AN UMa is a polar but still contains CaII lines. WZ Sge and V455 And show no signs of the secondary.



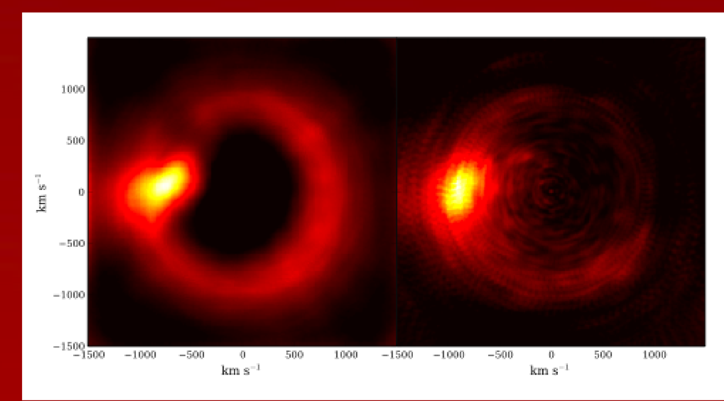


Figure 7: Left: Doppler maps for SU Uma where the Hγ map (left) shows a blurred disc, consistent with a system viewed at a low inclination. The CaII map (right) does not only show a disc ring but also the secondary star at K_2 ~ 250 km s^{-1}. Right: Doppler maps for WZ Sge where both the Hβ (left) and CaII (right) maps show a similar disc ring with a hotspot but no secondary star.

Future work

Preliminary analysis of our observed systems so far has shown the deductive power of the CaII triplet lines for the detection of secondary stars (and therefore K_2) in short orbital period systems over the commonly used Balmer lines. As the detection of even one mass ratio - superhump calibrator would restrict the empirical relation proposed by Patterson (2005) we submitted several proposals to observe potential candidates. We also will propose to get higher resolution spectra for GW Lib to better constrain q. A model based analysis should also give better insight into the origin and excitation of the CaII lines in these systems. And in the future, there is the potential to extend the survey to other systems like Black Hole X-Ray binaries as CaII has been detected in V404 Cyg.

With these tools, together with new instruments designed for fast spectroscopy, sampling the entire optical and infra-red window at high resolution, the number of binaries with known parameters should increase drastically.

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