Binary populations in SDSS: A new diagnostic for system parameters of evolved white dwarf binaries

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Evolved binary systems form a large subset of binary stars and Cataclysmic Variables (CVs) are a valuable sample within this group as they provide homogeneous configurations of white dwarfs plus near main-sequence mass donors. A key expectation based on our current understanding of binary evolution is that angular momentum loss drives CVs to short orbital periods as their donor stars shed mass. They provide the setting for the study of accretion onto compact objects, including Type Iasupernovae and gravitational wave emission. However, these short-period systems are faint as mass transfer rates drop. Hence, samples have traditionally been biased against them.

This has finally changed thanks to CV searches within SDSS as they are unearthing short-period systems in larger numbers. Although the orbital period is an important diagnostic, reliable mass estimates (e.g. mass ratio $q=M_{donor}/M_{WD}$) are needed to place a CV on its evolutionary track.

We have studied promising candidates at the bright end of the short-period binary sample, exploiting the Calcium II triplet lines in order to recover their binary parameters. The CaII lines offer advantages over the hydrogen and helium lines commonly used, as the latter are dominated by broad accretion disc profiles. Our data so far clearly vindicate this strategy, as most systems reveal sharp emission from the otherwise undetectable donors on top of the disc emission, allowing us to determine binary parameters in systems such as revealed by SDSS.

Method – GW Lib as ultimate test case

GW Lib is a dwarf nova system near the period minimum with $P_{orb}=76.8$ minutes. It was the first accreting binary found to contain a multi-period non-radial pulsating WD. We observed this system in 2007, 3 months after it went into super outburst ($\Delta mag \sim 9$) for the first time since its discovery outburst in 1983.

1 Strong and broad emission features are a common observational feature in CVs. Sources include the accretion disc, the hot spot and the secondary star. Taking successive spectra, motion due to the rotation of the binary is revealed, as emission lines are Doppler shifted as a function of the orbital period.

We show trailed spectra for GW Lib. Left the traditional Hβ line and right the normally ignored CaII line in the I-band. Where the Hβ line shows little structure, the CaII line shows a third emission peak on top of the double peaked profile from the accretion disc.

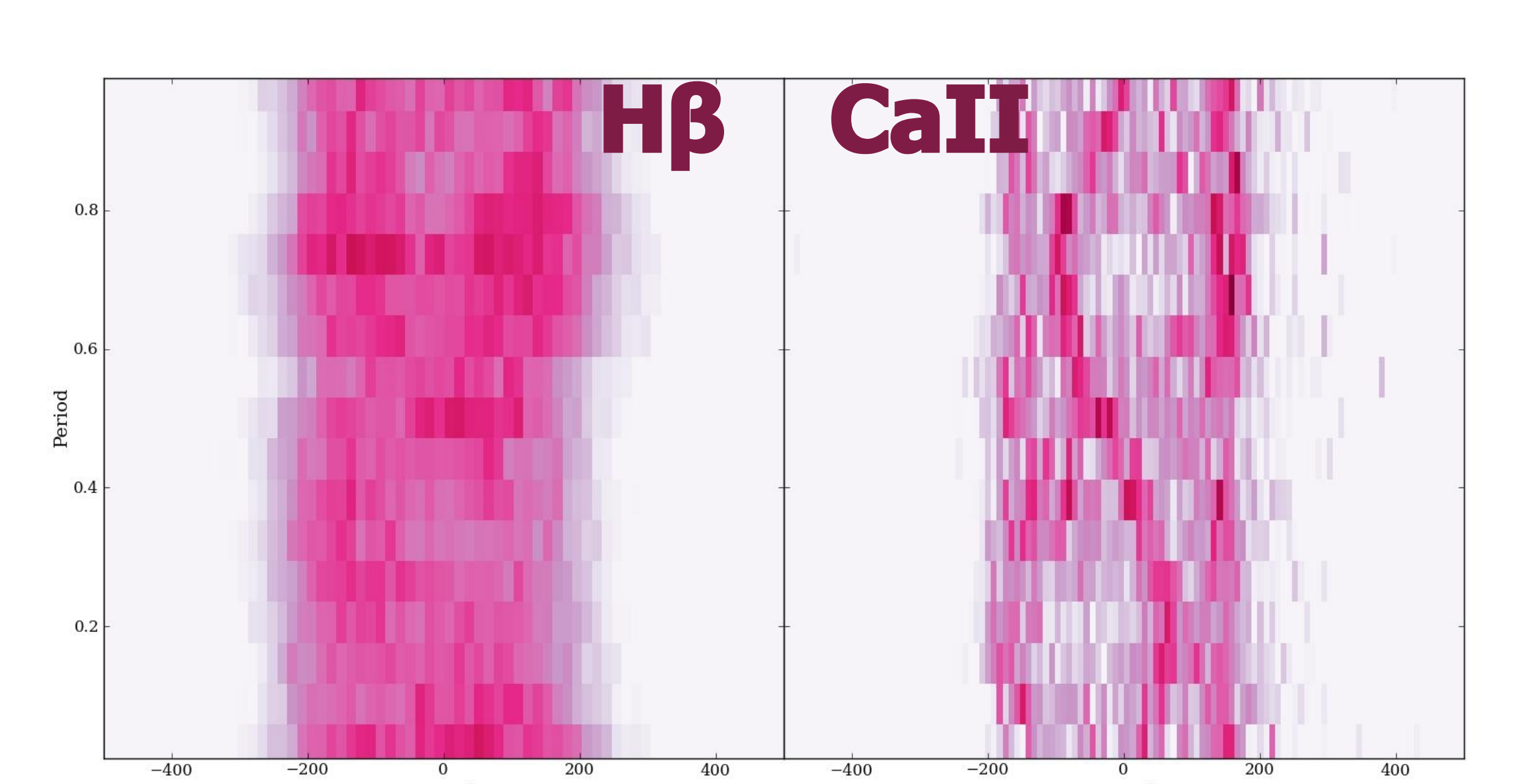
2 Knowing the Doppler shift as a function of the orbital period allows us to make a velocity-velocity map (Doppler Tomogram [3]) of the system. The different components (disc, WD, donor and stream) all project to unique positions in the map giving us an indirect tool to measure their projected radial velocities (K_{disc}, K_1, K_2 resp.) which provide an independent measure for $q = M_2/M_1 = K_1/K_2$.

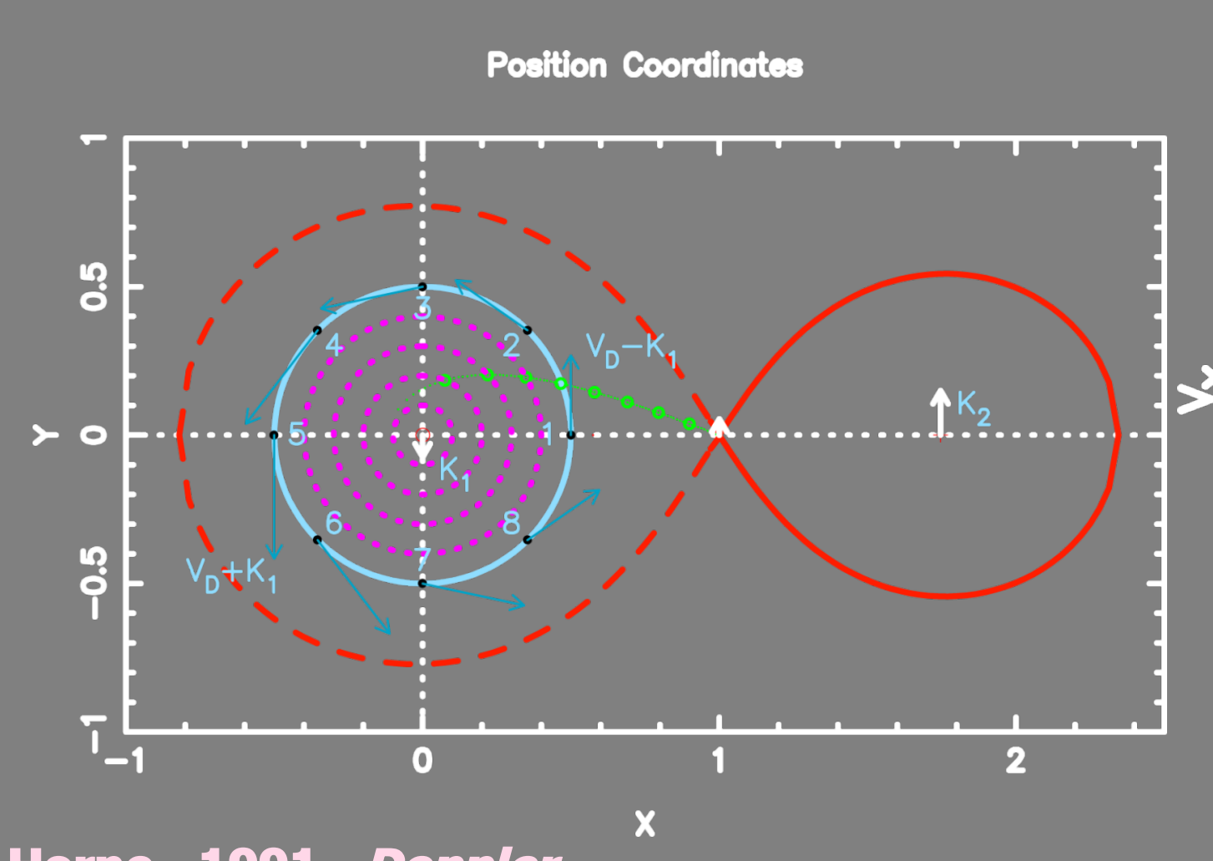
3 Using the trailed spectra for GW Lib, we constructed Doppler maps. Where the Hβ map only shows a broad disc, the CaII map not only has a finer structure in the disc, but also reveals the donor star in emission for the first time. Measuring the location of the emission (K_2), combined with a measure of the centre of the disc emission (K_1) gives us a first ever dynamical mass constraint at $q < 0.23$ [5].

4 We have also detected MgII (at 4481A) in absorption. This line is formed near the surface of the WD and is expected to be gravitationally redshifted in its deep gravitational potential. This redshift, combined with mass-radius models, gives a direct measure of the WD mass [7,9].

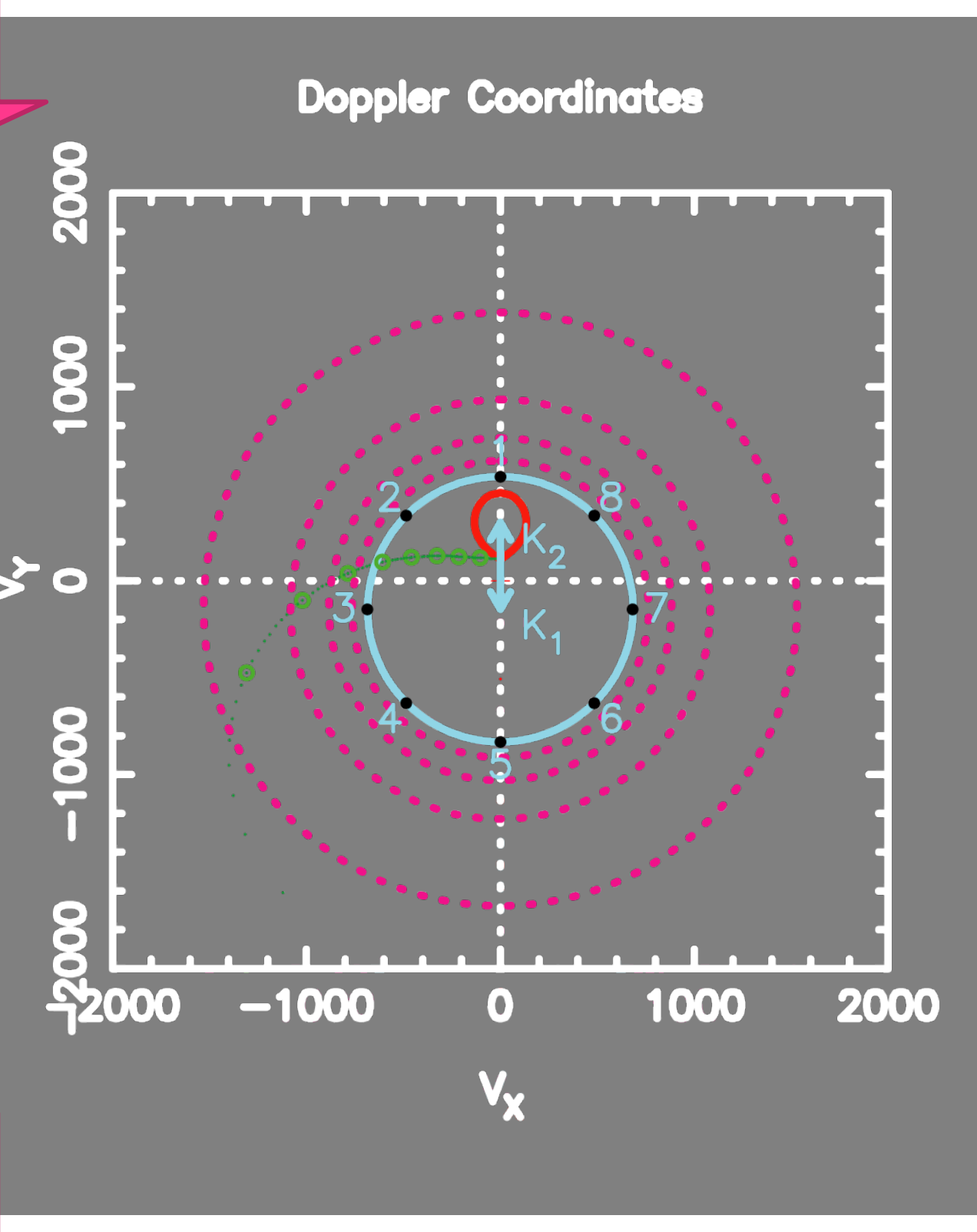
We measure $v_{grav} = 51.8 \pm 5.7$ km/s which is consistent with WD mass of $0.86 \pm 0.02\ M_{\odot}$ [6].

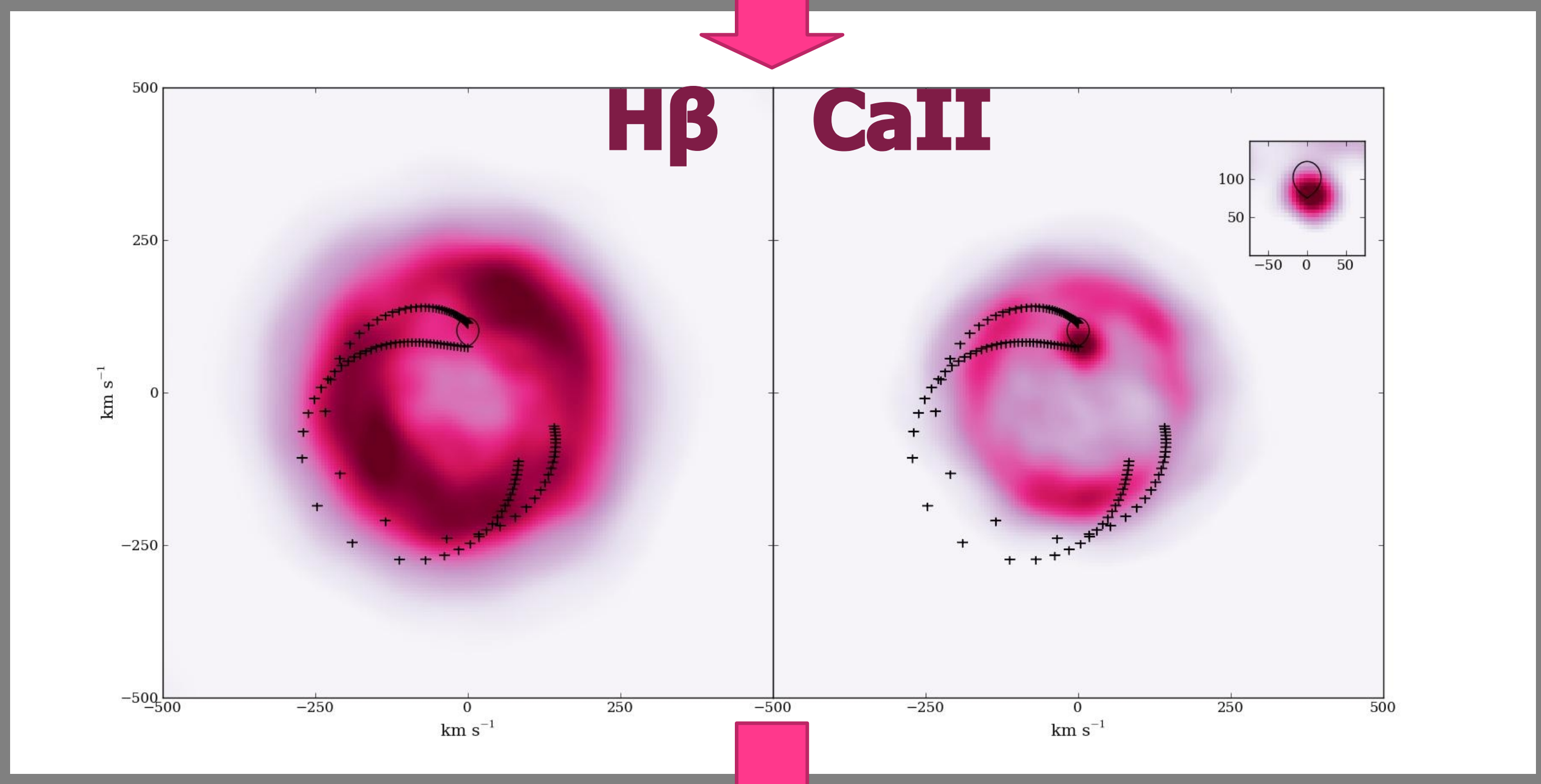
Unfortunately, the S/N is too low to detect any orbital variation of the WD in this line with certainty but suggest $K_1<12.1$ km/s. A simultaneous, time-resolved, detection of the donor in CaII and the WD in MgII will be pursued in May on the VLT. This could provide us with a non-superhump determined mass ratio and will unlock the system parameters for GW Lib.

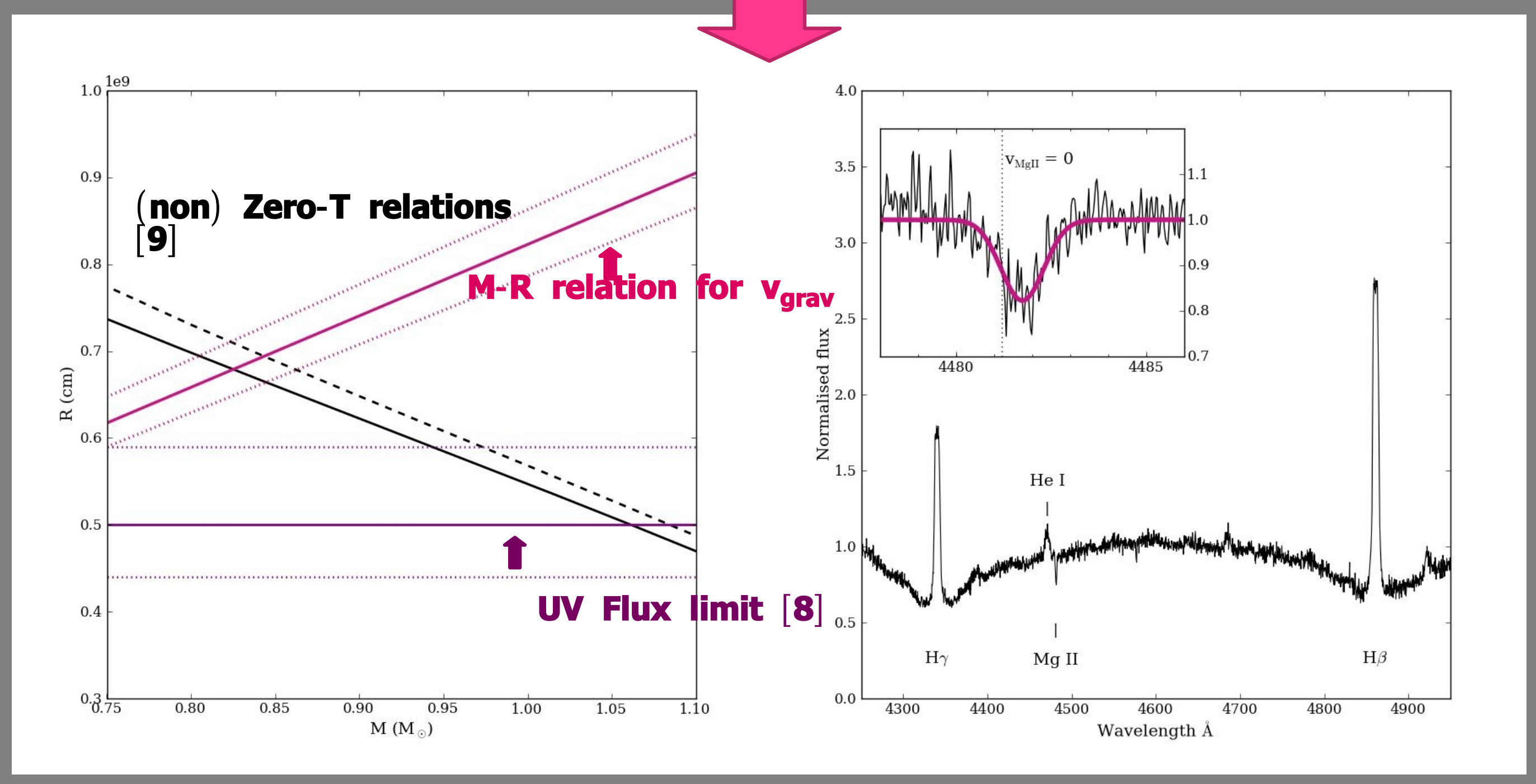




Horne, 1991, *Doppler tomography: it's easy, it's fun and everybody should try it!*







Binary evolution at short orbital periods

According to binary evolution models, the majority of CV population should have evolved towards short orbital periods, around 80 minutes. However due to the faintness of the depleted donors and the rare outbursts, few of these systems have been found. Recent studies, such as the Sloan Digital Sky Survey (SDSS), are finally finding short-period systems in larger numbers [1]. Although the orbital period is an important diagnostic, reliable mass estimates are needed to perform quantitative binary tests. The faintness of the low mass donor star in comparison to the WD and the accretion flow means that very few solid mass constraints are known in this regime. Only in 2006, the first secure CV with a brown dwarf donor was identified thanks to the tight mass constraints made possible because the system is eclipsing [2]. In contrast, the more typical candidates as WZ Sge remain difficult to constrain conclusively [7]. Patterson [4] has identified several potential low mass ratio candidates, but his method, which is based upon tidal instabilities in the disc, is indirect and poorly calibrated exactly at the small mass ratios which are the most relevant. If properly calibrated, it would offer mass ratio estimates for many systems.

Results

We have observed several short period CVs in the I-band exploring the diagnostic power of the CaII triplet lines. We find signatures of the irradiated side of the donor star in ~50% of the surveyed systems. These signatures make it possible to determine the system parameters in those systems where the absorption features of the donor star are undetectable. This enabled us to place a number of additional systems on their evolutionary tracks, providing vital information for our understanding of binary evolution.

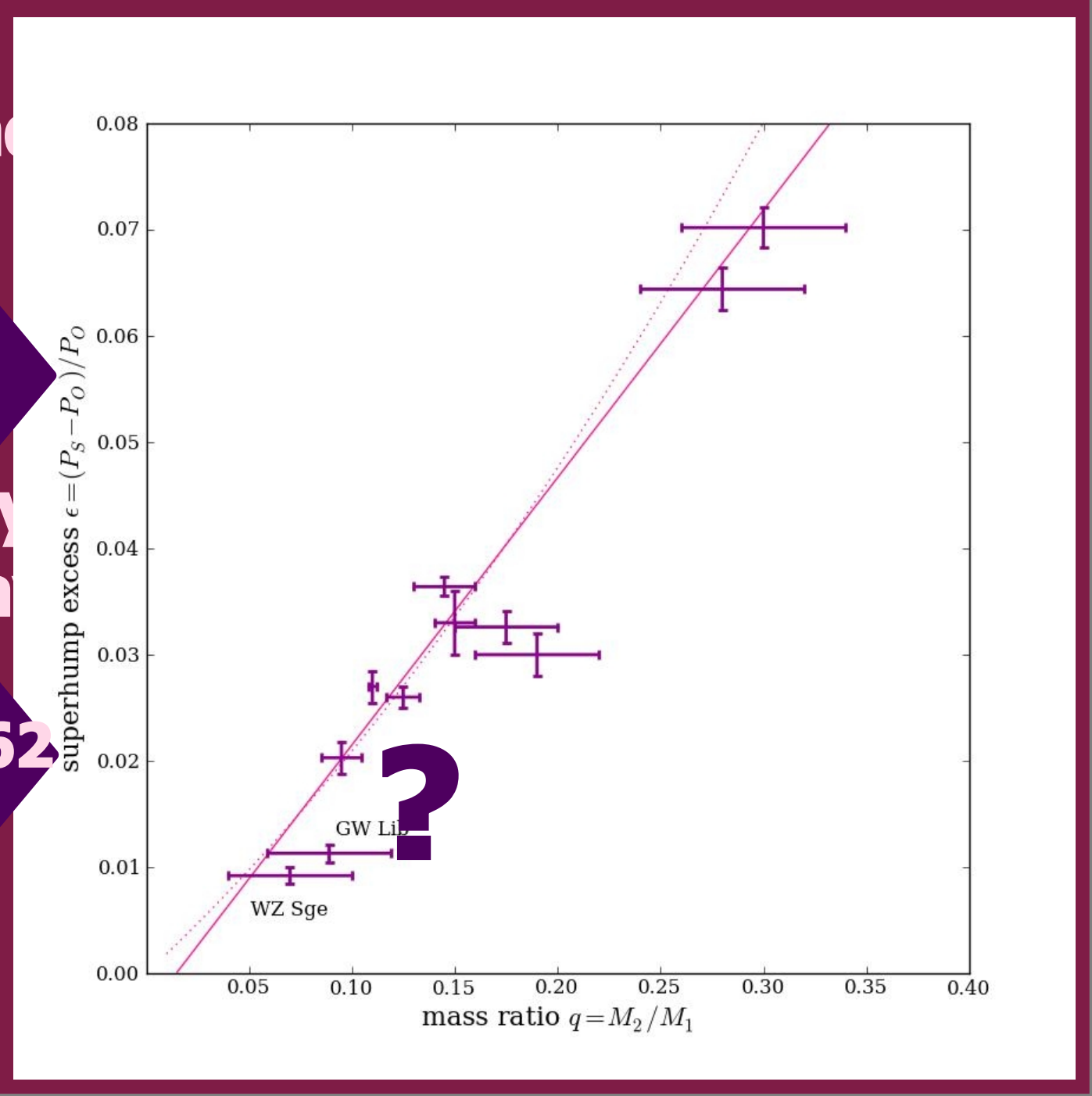
Even just one precise measure of a low q system will anchor the low mass ratio end of Patterson's empirical superhump relation, significantly improving the calibration as at the moment it hinges on the poorly determined mass ratio of WZ Sge [7].

For GW Lib we fin
$K_2=100.7$ km/s
$K_1<12.1$ km/s

$q_{dyn}<0.12$

P_{orb} = 0.05332 day
P_{sh} = 0.053925 da

q_{sh} = 0.062



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