Evolutionary status of WZ Sge

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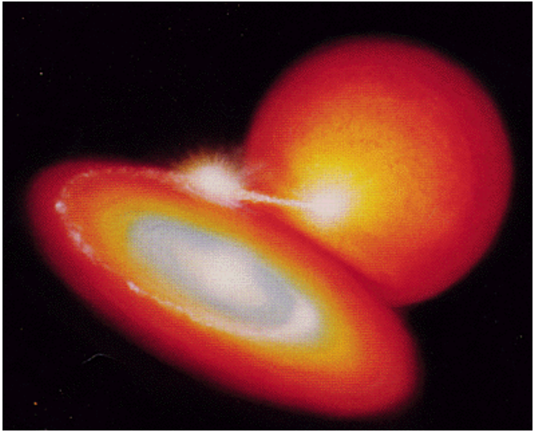
Cataclysmic variables

Classical novae = One recorded outburst
Recurrent novae = Several recorded outbursts
Dwarf novae = Recurrent outbursts of smaller magnitude.

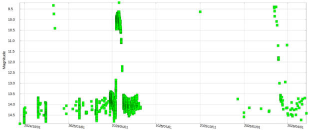


Dana Berry, STScI

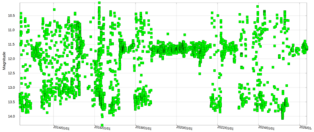
Dwarf novae

Dwarf Novae

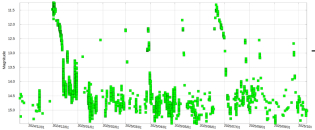
U Gem: Normal outbursts



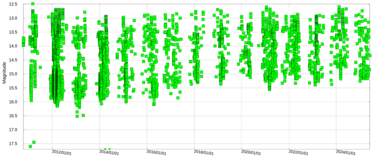
Z Cam: Standstills



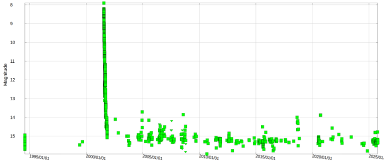
SU UMa: Superoutbursts



ER UMa: Superoutburst cycles < 100 d



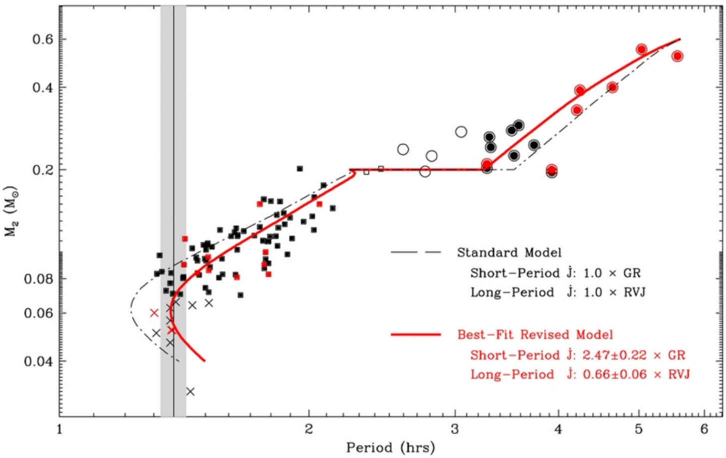
WZ Sge: Only superoutbursts, >10 yr cycles



CV evolution track

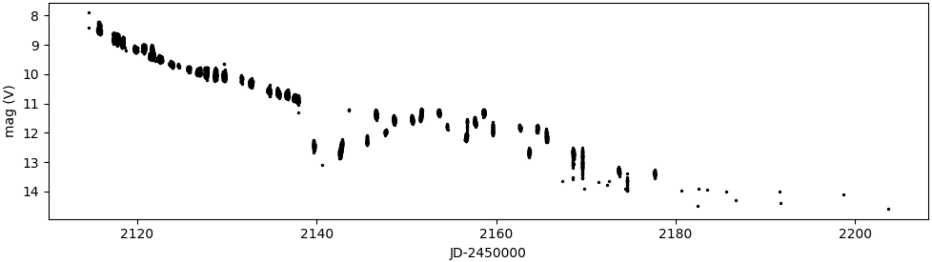
Period bouncers = DNe evolved past the period minimum.

Problem: There should be plenty, but we observe very few. Determining the evolutionary status of the donor is difficult, as it is very faint.



Knigge, Baraffe & Patterson 2011

WZ Sge-type dwarf novae



- Only superoutbursts with long intervals from years to decades.
- Large superoutburst amplitude (>6 mag), sometimes up to 9-10 mag
- Superoutburst duration > 3 weeks
- Some objects have multiple rebrightenings after initial superoutburst

- Short-period (P<90 min) dwarf novae
- Extremely low mass transfer rate of $\dot{M} \sim 10^{-13} M_{\odot} yr^{-1}$.

WZ Sge

- Orbital period 81.63 minutes
- V mag $\sim$ 15
- Inclination 75.89^{o} (Skidmore et al. 2002)
- Distance 45.17 pc (GAIA)
- Superoutbursts in 1913, 1946, 1978, 2001; intervals 33, 32, and 23 years.
- One of the brightest and most studied DNe -> easy to find good archival data

- Defining **accurate system parameters** and measuring accretion disk properties of WZ Sge throughout quiescence and **especially just before an outburst** should provide insight into unknown outburst mechanisms (more in **Veera Vuolteenaho**'s presentation soon!).

Previous measurements

Ref.	M_1	M_2	q	K_1	K_2	γ	i
Gilliland et al. 1986	$0.5 - 1.2$	$0.06 - 0.11$		49 ± 6		-72 ± 3	
Smak 1993	0.45 ± 0.19	0.058 ± 0.023	0.13^*				75 ± 2
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Steeghs et al. 2007	0.84 ± 0.04	0.078 ± 0.06	0.092 ± 0.008	47 ± 3	510 ± 10		
Harrison 2017					525 ± 11		
Pala et al. 2022	0.80 ± 0.02						
Georganti et al. 2022						-73 ± 3	

Previous measurements are not consistent with each other. What's wrong?

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Uses H_α wing fitting, not accurate if inner disk structure is non-Keplerian, inclined, or otherwise non-symmetrical.

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Uses Gilliland et al. results; also notes that their measurements depend on K_1 and value of phase shift between hotspot eclipse and WD eclipse. Not really reliable.

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Measure by fitting model hotspot stream on top of observed Doppler map hotspot tail; not very accurate method, HS structure may vary.

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Measured H_α peak-to-peak velocity and calculated M_1 from there; should be a decent estimate

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Valid estimates based on radial velocity measurements and Doppler tomography. However mass ranges are large.

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Used eclipse timing. They assumed a disk geometry where outer edge is at 3:1 resonance. However in WZ Sge-types, the disks may extend beyond that. These should be considered as lower limit.

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Measured using absorption lines that do not originate from the WD. Rest of the parameters are calculated from K_1 measure together with results of Steeghs et al. 2001.

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Measured using K I NIR doublet. Likely an upper limit to donor motion.

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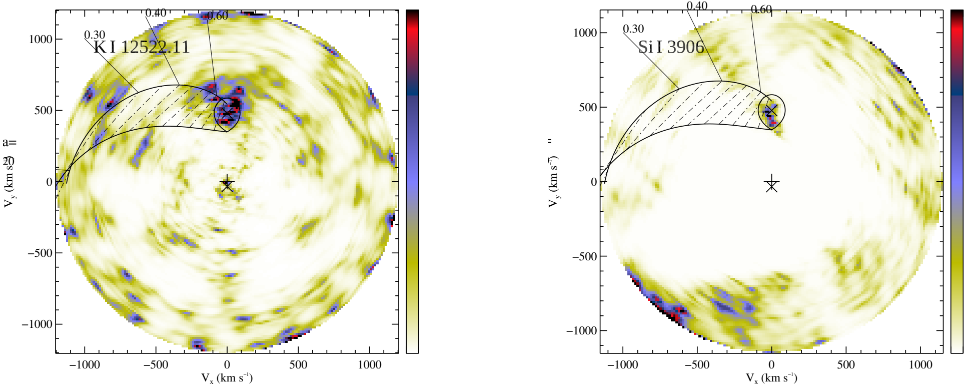
Used UV spectral fitting. Should be a semi-reliable number.

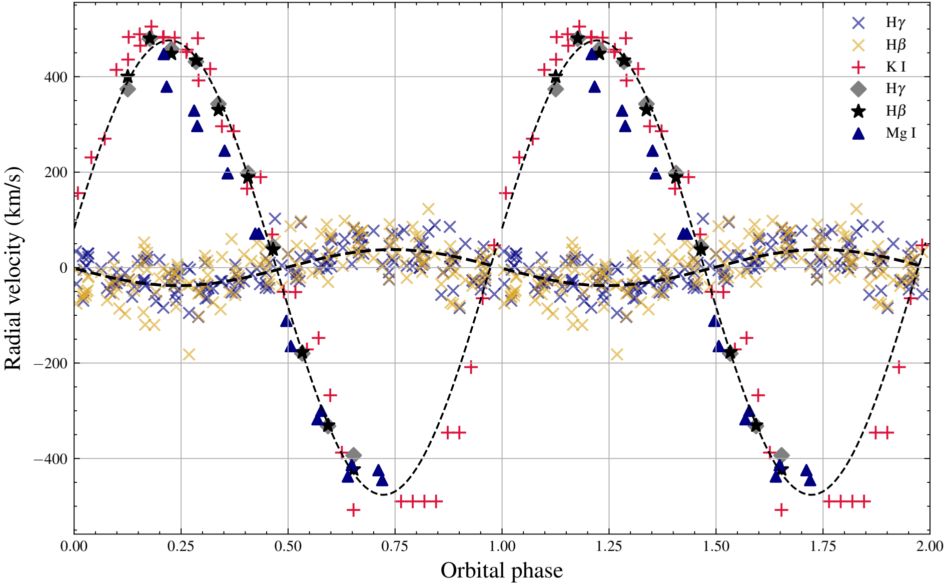
The Donor



Measured radial velocity depends on where on the donor surface the absorption/emission originated from.

→ To get accurate radial velocity measurements, we need to measure several different lines.

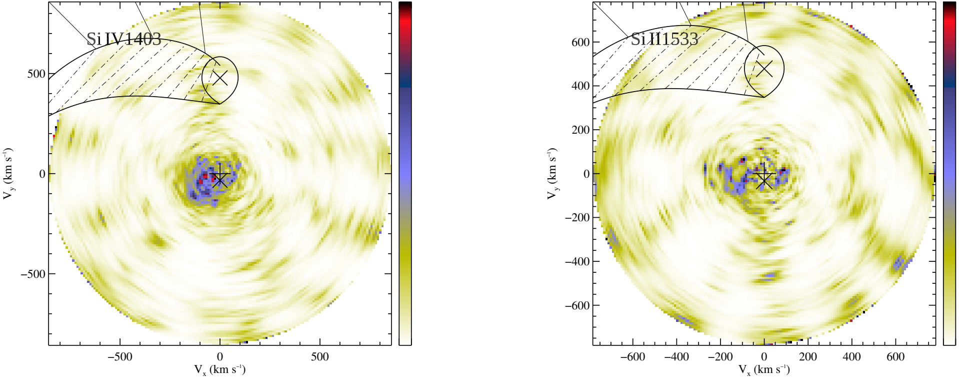
The Donor



Hγ
Hβ
K I
Hγ
Hβ
Mg I
400
200
0
−200
−400
Radial velocity (km/s)
0.00
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
Orbital phase

The WD and UV disaster

Gravitational redshift from WD absorption lines is commonly used to measure the WD mass.



The lines used in previous studies do not originate from the WD!

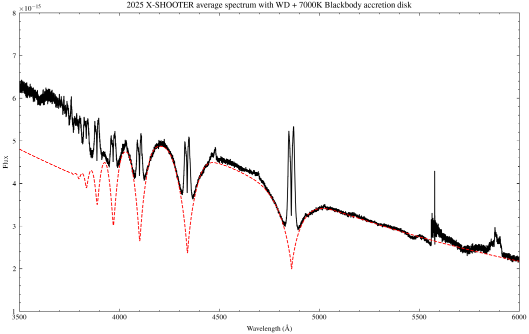
Measuring WD properties

If we cannot use UV absorption lines, then what?

M_1 can be obtained from fitting model WD atmospheres to optical spectra.

Best-fit achieved with log g=8.3, resulting in WD mass $M_1 = 0.8$

This supports the result of Pala et al. (2002), who found the same WD mass with UV spectral fitting.



Measuring WD properties

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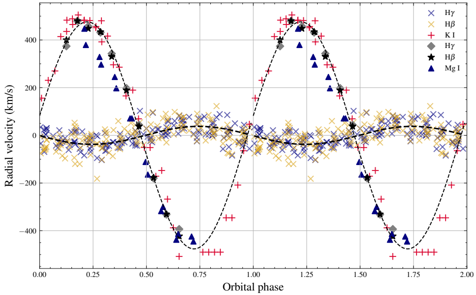
K_1 can be estimated from wide Balmer absorption lines.

Best-fit sinusoid to H_β and H_γ lines provide $K_1 = 37$ km/s.

However, these lines may originate from different atmospheric heights in the WD
$\rightarrow$ Will cause some error in the final K_1 measurement



Masses from dynamical limits

With $P = 0.05668784695\,\text{d}$ (Patterson et al. 2018), $K_1 = 37\,\text{km/s}$, $K_2 = 480 - 510\,\text{km/s}$ (needs more research to narrow down), and $i = 75.89°$, we get mass ranges:

$$M_1 = 0.82 - 0.98 M_\odot$$

$$M_2 = 0.063 - 0.071 M_\odot$$

$\rightarrow$ Donor under the hydrogen-burning limit!

$$M_1 = \frac{P K_2 (K_1 + K_2)^2}{2\pi G \sin^3 i}$$

$$M_2 = \frac{P K_1 (K_1 + K_2)^2}{2\pi G \sin^3 i}$$

Current system parameters

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New measurements	0.8 ± 0.07	$0.058 - 0.065$		37 ± 3	$480 - 510$		

Conclusions

- We cannot trust the UV absorption lines that are commonly used to measure WD mass and radial velocity, as they seem to not originate from the WD.
- The donor in WZ Sge is clearly visible in multiple optical/NIR spectral lines, and can be used to measure its orbital motion.
- Based on our system parameters, WZ Sge seems to be a post-bounce system.
- We have a waiting observing campaign in July 2026 with NOT to study the inner accretion disk structure in detail.