Z And-type outbursts in accreting white dwarf binaries

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1. Accreting white dwarf binaries producing thermonuclear outbursts: Symbiotic Stars (SySts) & Cataclysmic Variables (CVs)

2. The response of a white dwarf to mass accretion

3. Z And-type outbursts in SySts and in a CV, V1047 Cen

4. Conclusions

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Accreting white dwarf binaries:

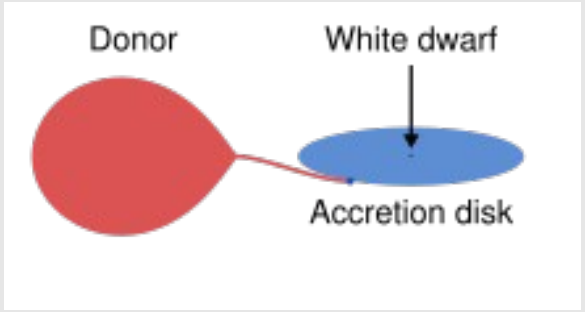
Cataclysmic variables (CVs) & S*ymbiotic stars* (SySts)

I. Configuration and basic parameters

Binary	Porb	Donor	Accretor	MTM	(dM/dt)acc	Outburst
CVs	hours	MS	WD	L_1	10^{-8}-10^{-10}	Cls. nova
SySts	years	RG	WD	wind	10^{-7}-10^{-8}	Z And-type

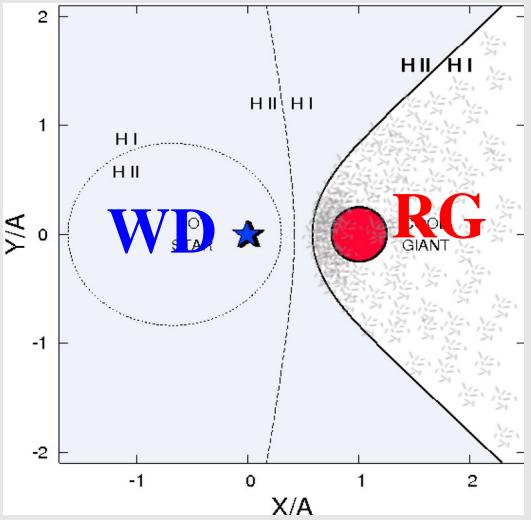
MTM – mass transfer mode
(dM/dt)acc in M_{Sun}/year

Cataclysmic variable



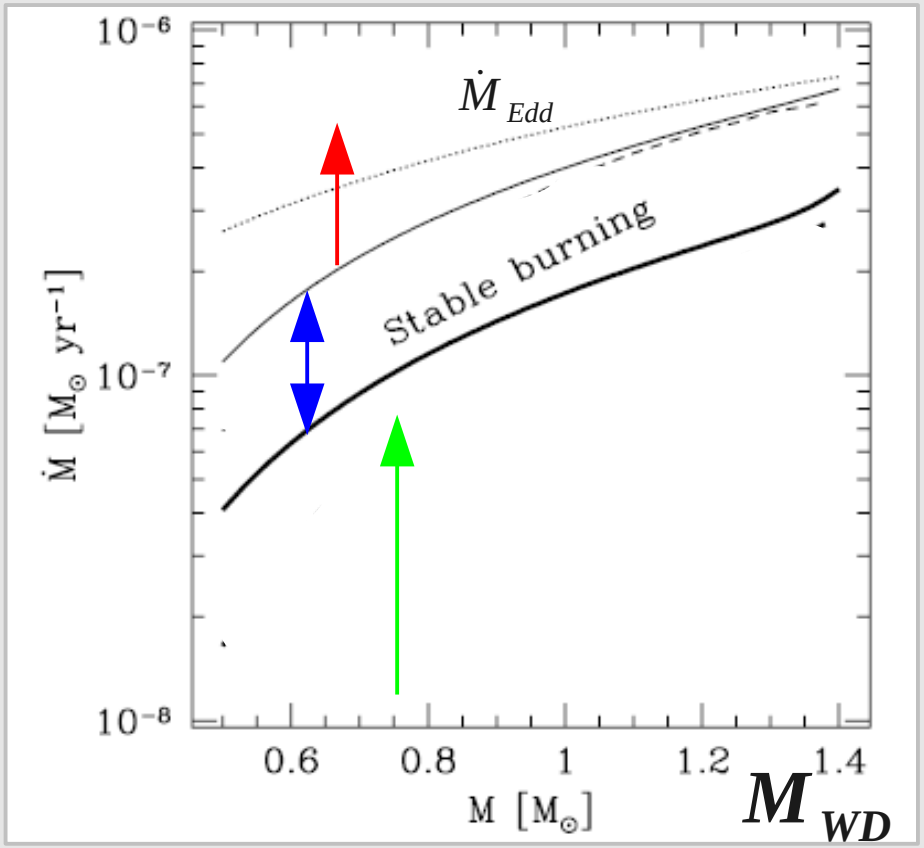
A ~ a few solar radii

SySt: quiescent phase



A ~ a few AU (or more)

A white dwarf's response to mass accretion



Shen & Bildsten 2007, ApJ, 660, 1444;
Nomoto et al. 2007, ApJ, 663:1269;
Wolf et al. 2013, 777:136

Accreting WD increases its mass:

(i) at low rates up to $\Delta M \rightarrow P_{crit}$:
ignition of a nova outburst

(ii) at high rates of ~10^{-7} M_{Sun}/year:
stable H-burning in a shell

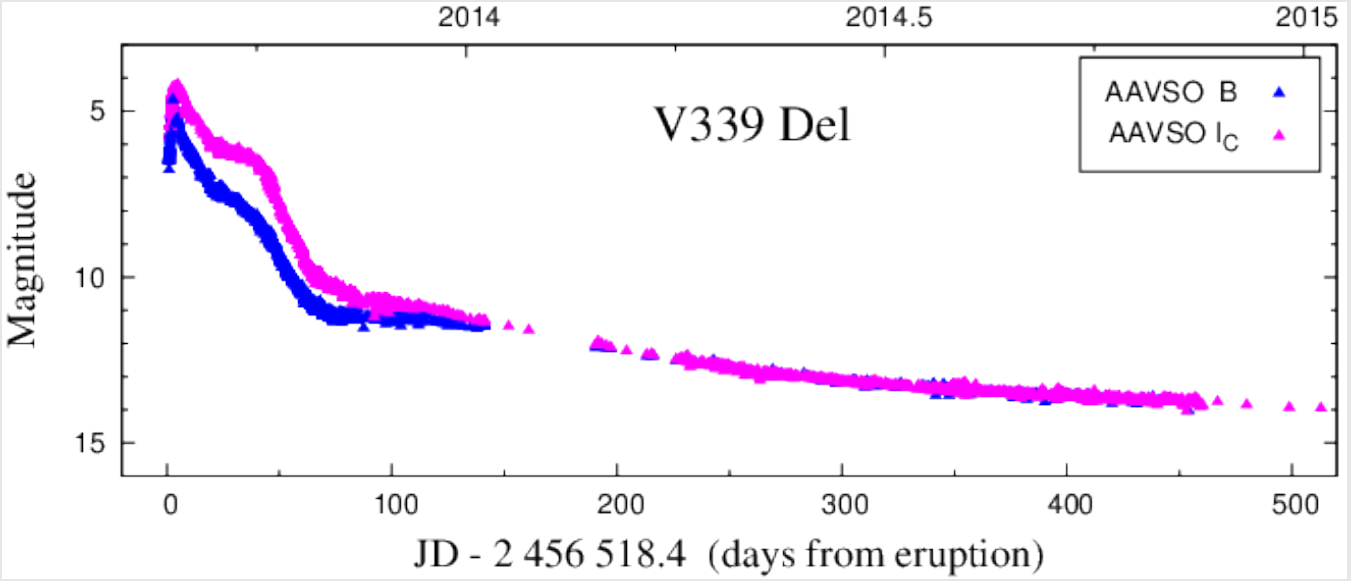
(iii) if rates >~10^{-7} M_{Sun} /year:
Z And-type outbursts

(e.g., Paczynski & Zytkow 1978, ApJ, 222, 604; Yaron, et al., 2005, ApJ, 623, 398; Hachisu et al., 1996, ApJ, 470:L97; Skopal et al. 2017, A&A, 604, A48)

$$L_{WD} = L_{acc.} + L_{nucl.} = G\frac{M_{WD}\dot{M}_{acc}}{R_{WD}} + \eta X \dot{M}_{acc} \quad \left(\eta = 6.3\times10^{18}\,\mathrm{erg/g},\ X \equiv 0.7\right)$$

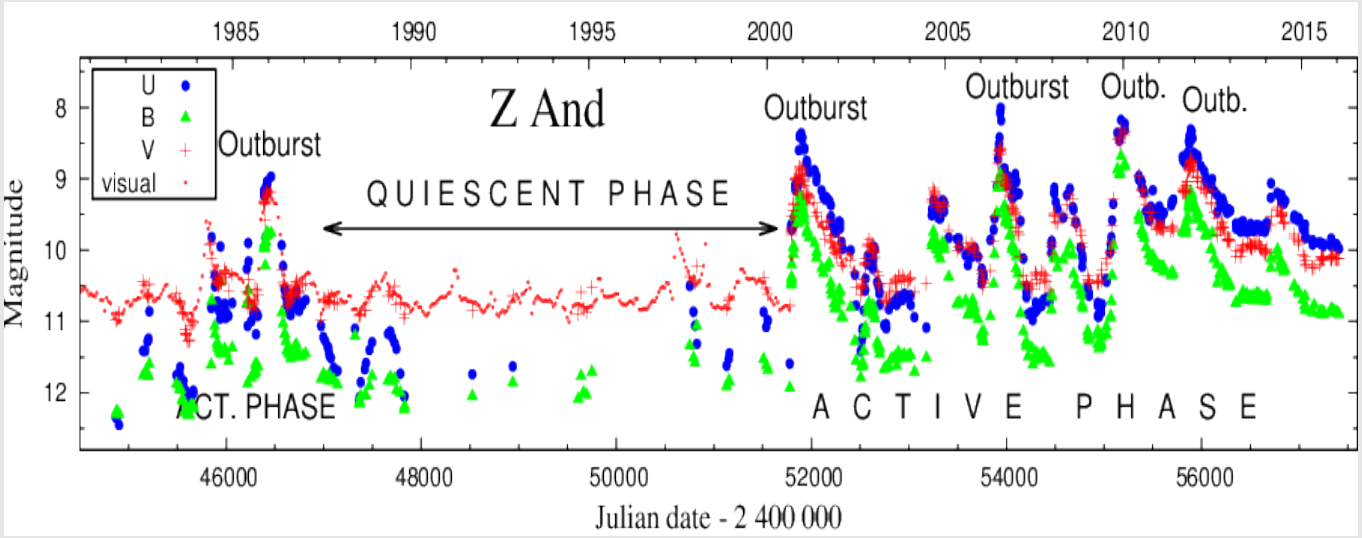
Generated energy: ~ L_{WD} + energy to lift off ΔM_{wind}

Classical nova (in CVs) & Z And-type (in SySt) outbursts:
1. Photometric evolution



Classical nova V339 Del

$\Delta\mu \sim 12 - 13$ mag
$L \sim 10^{38-39}$ erg/s $> L_{Edd}$
Mass outflow:
$\sim 10^{-4}\ M_{Sun}$/year

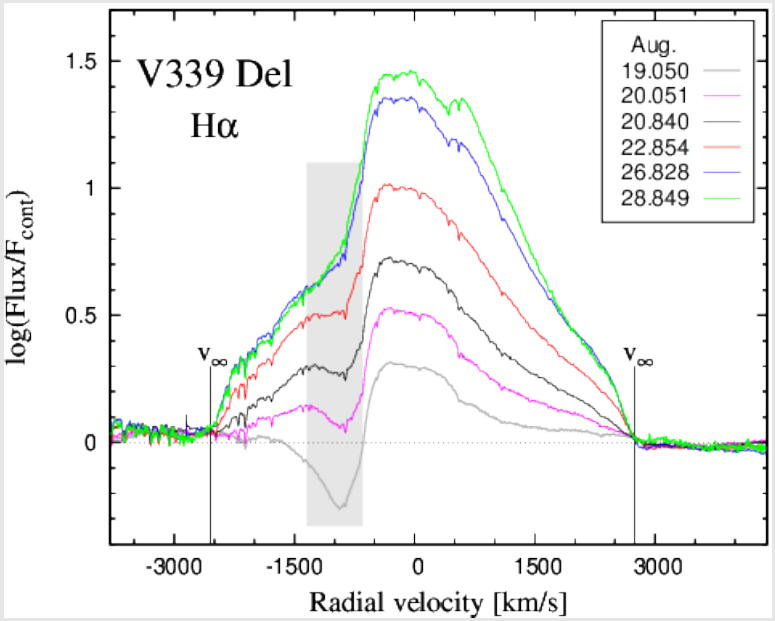


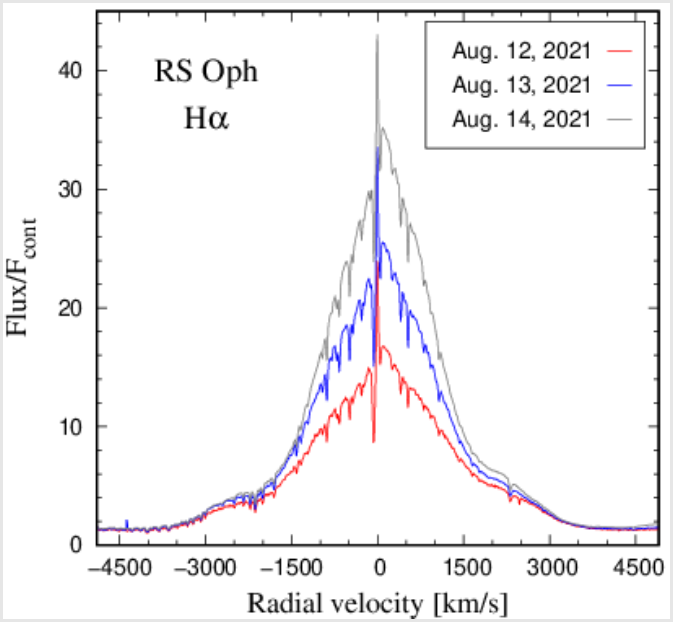
Z And type outburst in the SySt Z And

$\Delta\mu \sim 1 - 3$ mag
$L \sim 10^{37}$ erg/s $< L_{Edd}$
Mass outflow:
$\sim 10^{-6}\ M_{Sun}$/year

Major diversity: violence of outbursts

Classical nova (in CVs) & Z And-type (in SySts) outbursts:
2. Spectroscopy: broadening of emission line profiles





(Skopal et al., 2014)

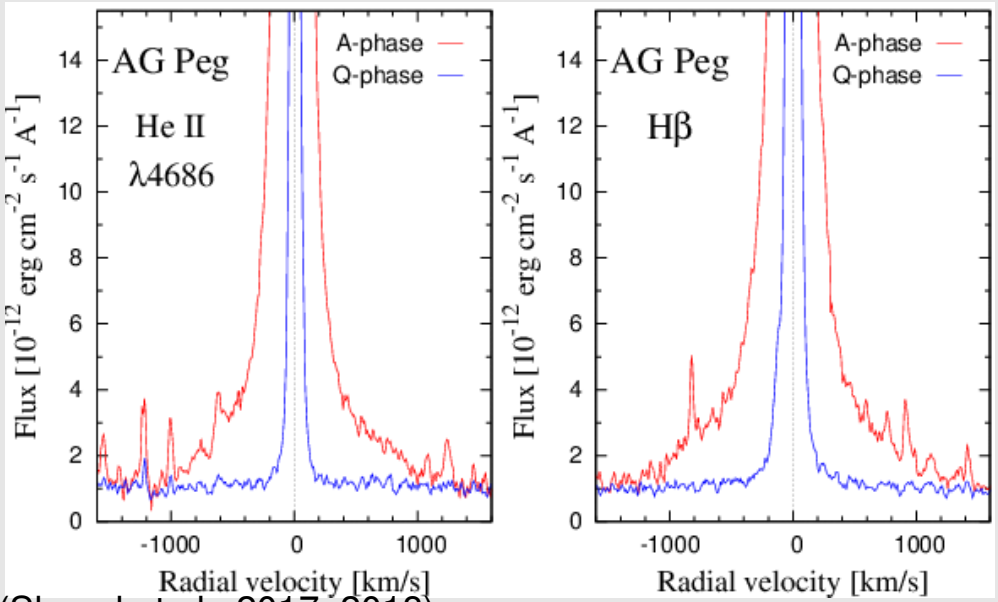
Nova outbursts:

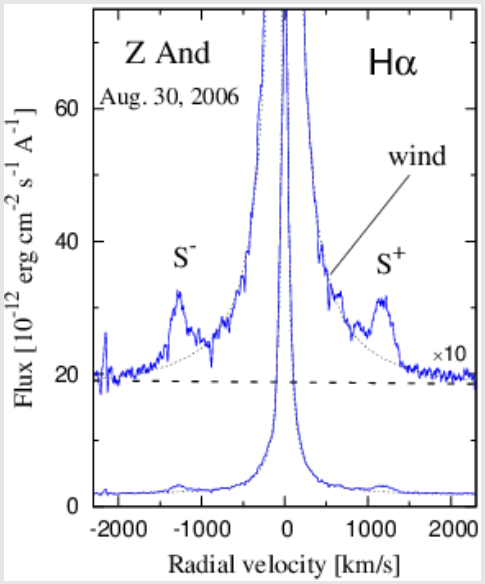
Classical nova V**339 Del** (Nova Del 2013):

v_∞ ~ 2600 km/s

Recurrent Symbiotic nova **RS Oph:**

v_∞ ~ 4000 km/s





(Skopal et al., 2017, 2018)

Z And-type outbursts

SySt **AG Peg**, 2015 outb.

v_∞ ~ 1200 km/s

SySt **Z And**, 2006 outb.

v_∞ ~ 2000 km/s

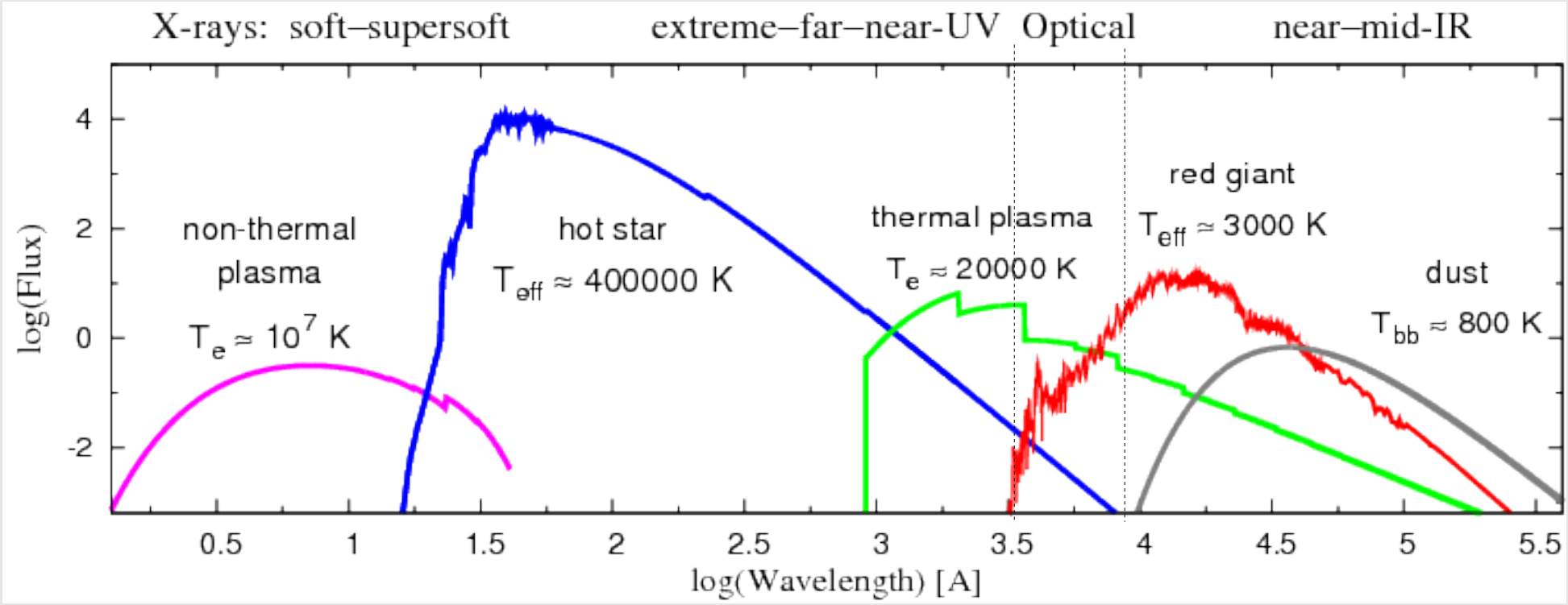
&

bipolar jets: ±1200 km/s

Classical nova (in CVs) & Z And-type (in SySts) outbursts:
3. Spectral energy distribution in the continuum

Different components of radiation are evolving in time

$$F(\lambda) = F_{WD}(\lambda) + F_N(\lambda) + F_G(\lambda) + F_D(\lambda)$$

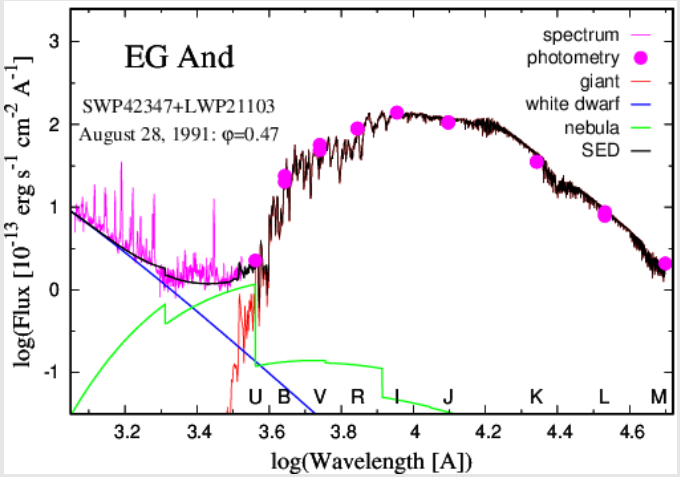


Aim: disentangling the composite spectrum to obtain physical parameters of individual components of radiation

Can the WD in SySts produce nova-type outbursts?
1. Observational manifestation of mass accretion onto WD in SySts

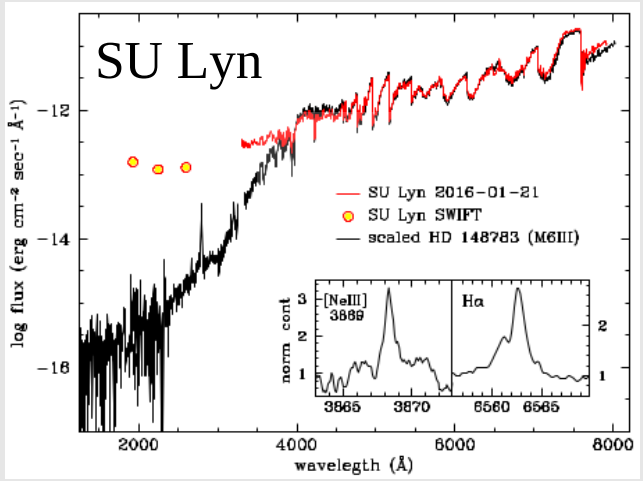
$\dot{M}_{acc} < \dot{M}_{stable}$ + $P_b < P_{crit}$: ***Accretion – powered*** (accreting-only) SySts
e.g., EG And, SU Lyn, CQ Dra, hidden SySts)

Weak or no activity in the optical, but a strong excess and variability in the UV—X-rays.
(e.g., Skopal, A. 2005, ASP Conf. Ser. 330, 463; Munari et al. 2021, MNRAS, 505, 6121; Perko, M. 2024, CoSka, 54, 75)



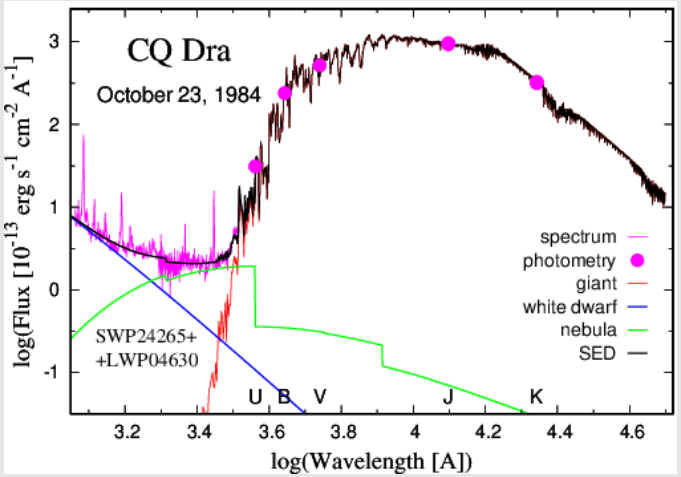
M3III + WD, $P_{orb} = 482$ d, eclipses,
$L \sim 2.5 \times 10^{35} (d/590\,\mathrm{pc})^2$ erg/s,
orbital-related var. of the opt. em. l.

Vogel, M. 1991, A&A, 249,173;
– 1992, A&A, 260, 156;
Kenyon & Garcia, 2016, AJ, 152, 1;
Shagatova et al. 2016, A&A, 588, A83;
– 2021, A&A, 646, A116.



M5.8III + WD, variable UV ,
$L_{UV} \sim 1 \times 10^{34} (d/640\,\mathrm{pc})^2$ erg/s,
variable opt. emission lines.

Mukai et al. 2016, MNRAS, 461, L1;
Lopes de Oliveira et al. 2018, ApJ, 864:46;
Kumar et al. 2021, MNRAS, 500, L12
Ilkiewicz et al. 2022, MNRAS, 510, 2707

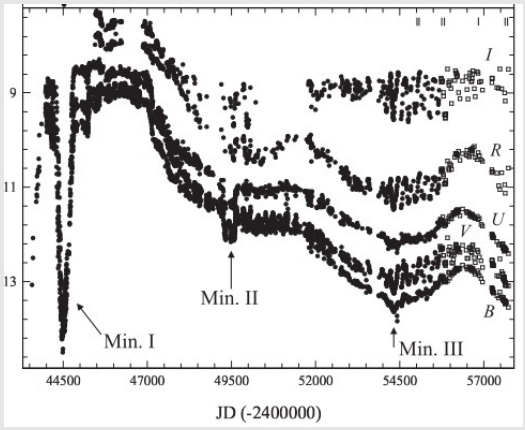


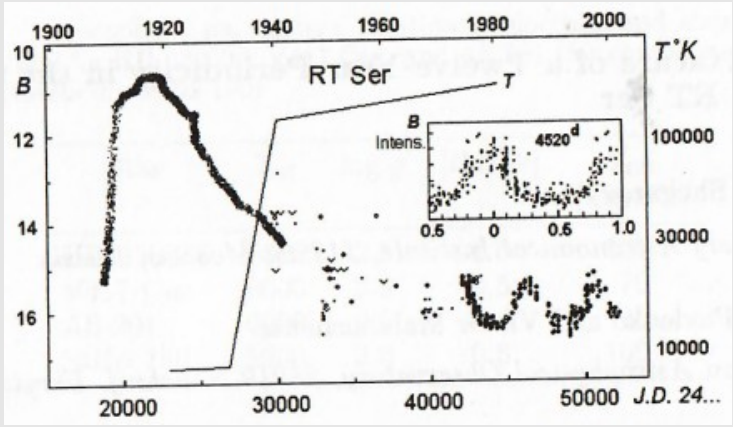
M3III + WD, $P_{orb} = 1703$ d,
$L \sim 2.5 \times 10^{34} (d/178\,\mathrm{pc})^2$ erg/s,
variable nebular continuum.

Reimers, D. 1985, A&A, 142, L16;
Wheatley et al. 2003, MNRAS, 346, 855;
Skopal, A. 2005, ASP Conf. Ser. 330, 463;
– 2005, A&A, 440, 995;

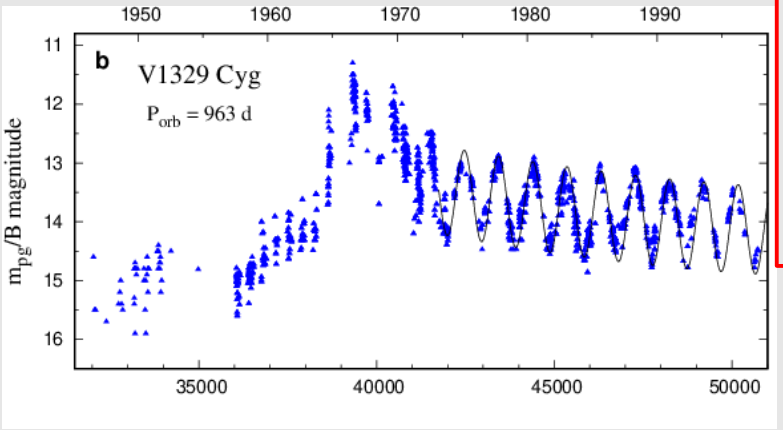
Can the WD in SySts produce nova-type outbursts?
2. Yes, they are called “symbiotic novae” (SyNe)

PU Vul:
M6III + WD
P_{orb} = 4897 d
Post-outburst:
EM ~ 10^{60} cm^{-3}
L_{WD} ~ 3000 L_{solar}
(Tatarnikova et al., 2018; Muerset & Nussbaumer, 1994; Cuneo et al. 2018)

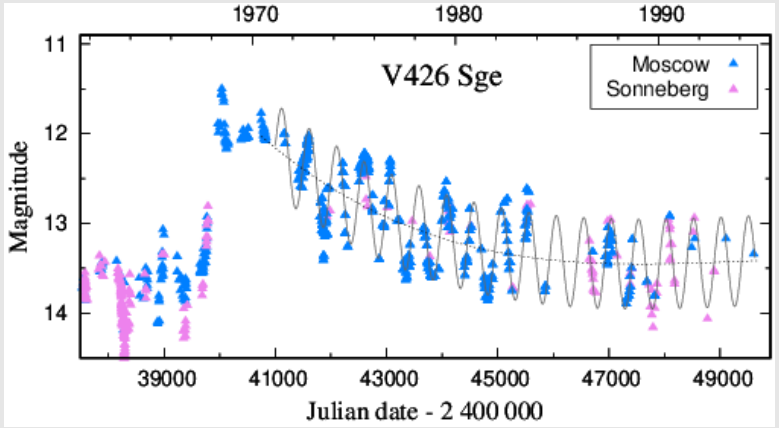




RT Ser:
M5.5III + WD
P_{orb} = 4431 d
Post-outburst:
L_{WD} ~ 3300 L_{solar}
(Shugarov et al. 2003; Muerset & Nussbaumer, 1994)



After the SyN outburst, the accretion usually stabilizes at the level of steady burning WD:
L ~ L_{stable}
a few x 10^3 L_{Sun}



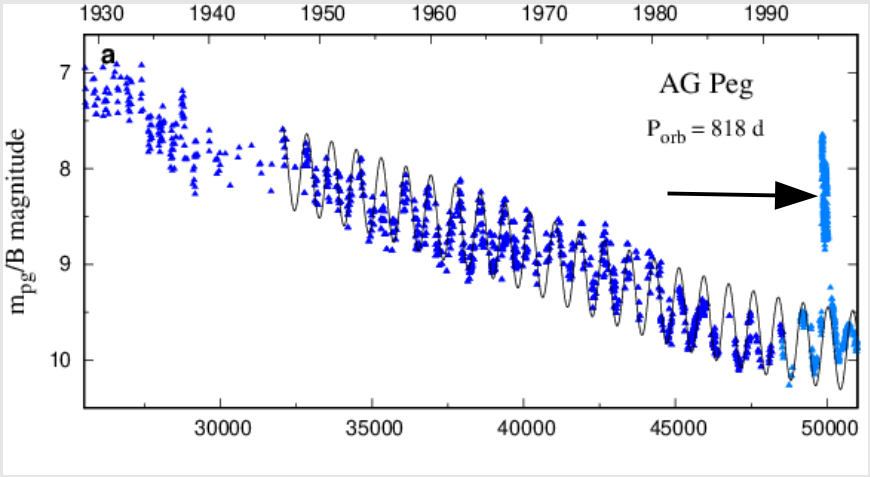
V1329 Cyg: M6III + WD, P_{orb} = 960 d,
Nova outburst in 1964; eclipsing;
Post-outburst: L_{WD} ~ 7000 L_{solar}, EM ~ 10^{60} cm^{-3}, T_{BB} ~ 170 kK, R_{WD} ~ 0.1 R_{solar}.

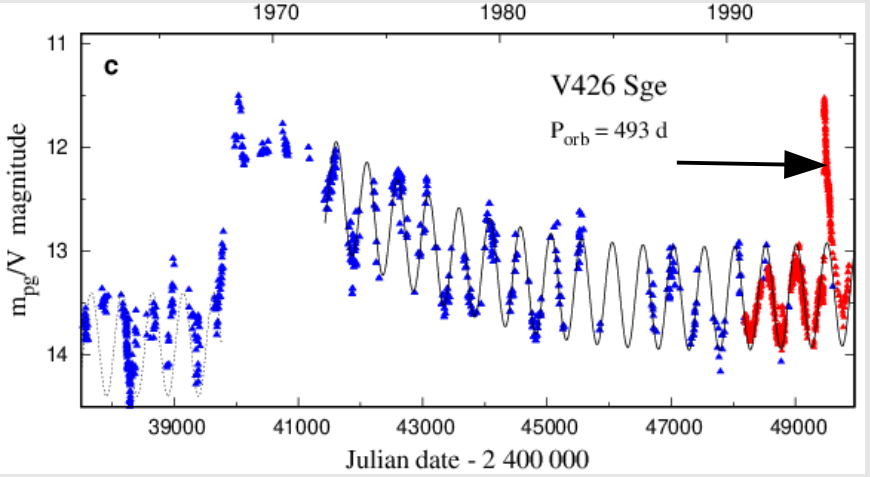
(Munari et al. 1988, A&A, 202, 83; Muerset & Nussbaumer, 1994, A&A, 282, 586; Schild & Schmid, 1997, A&A, 324, 606; Skopal, A. 2005, A&A, 440, 995)

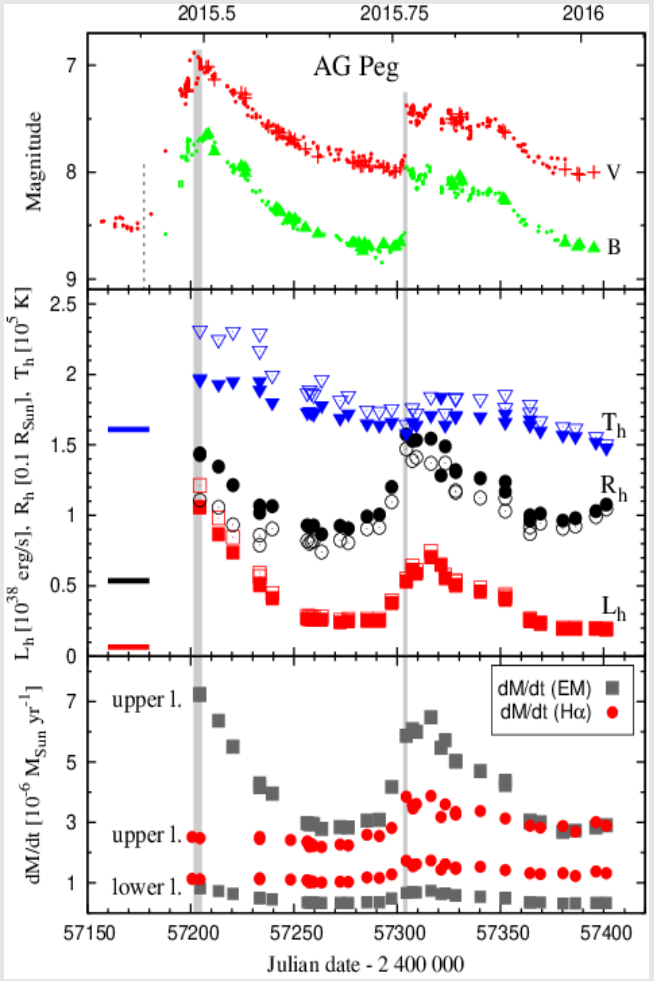
V426 Sge: M4.8III + WD, P_{orb} = 494 d,
Nova outburst in 1968, non-eclipsing,
Post-outburst: L_{WD} ~ 2000 L_{solar}, EM ~ $10^{59\text{-}60}$ cm^{-3} , T_{BB} ~ 150 kK, R_{WD} ~ 0.07 R_{solar}.

(Adapted according to Skopal et al. 2020, A&A, 636, A77)

Post SyN evolution: If transiently $\dot{M}_{acc} > \dot{M}_{stable} \rightarrow$ **Z And-type outbursts** occurs.







If $\dot{M}_{acc} \succ \dot{M}_{stable}$,

optically thick **wind blows** from the WD at

$$\dot{M}_{wind} \gtrsim 10^{-6}\, M_{sun}/\,year$$

and

$$L_{WD} \sim 10^{37-38}\, erg/\,s$$

(see, Hachisu et al. 1996).

These parameter values are determined during Z And-type outbursts (here AG Peg).

What ignites the outburst?

(i) A disruption of the AD → infall of H-rich material onto the WD.

(ii) Variation in the mass-transfer from the red giant.

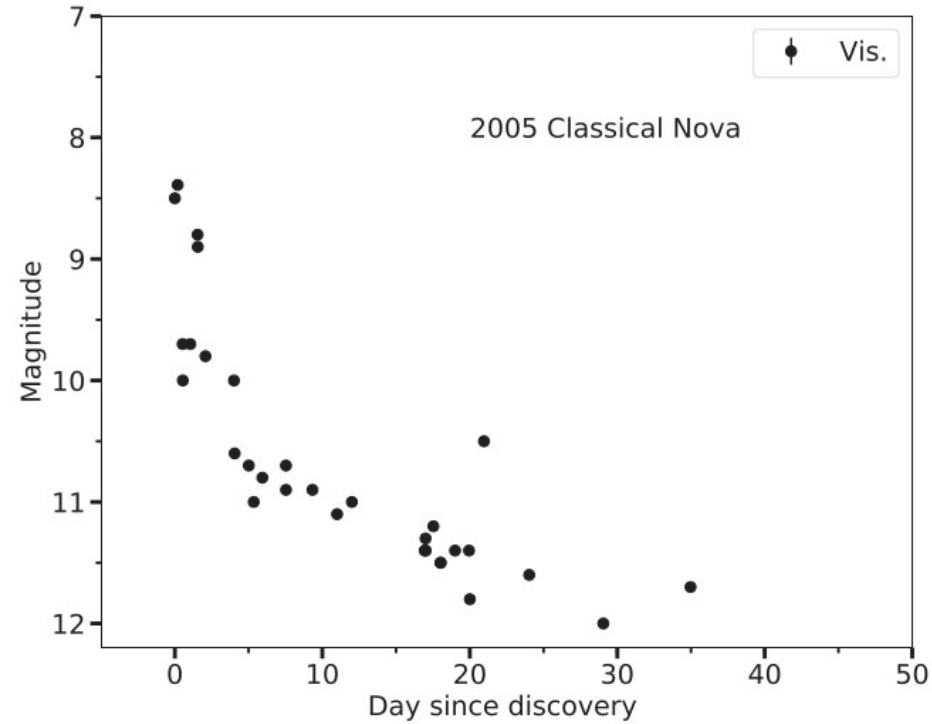
(Sokoloski et al. 2006; Bisikalo et al. 2006)

Figure.
Left: Transition from the symbiotic nova outburst to quiescence and to Z And-type outburst for AG Peg (top) and V426 Sge (bottom).
Right: LC and L, R, T, and dM/dt parameters for AG Peg during its 2015 outburst (Skopal et al. 2017, 2020).

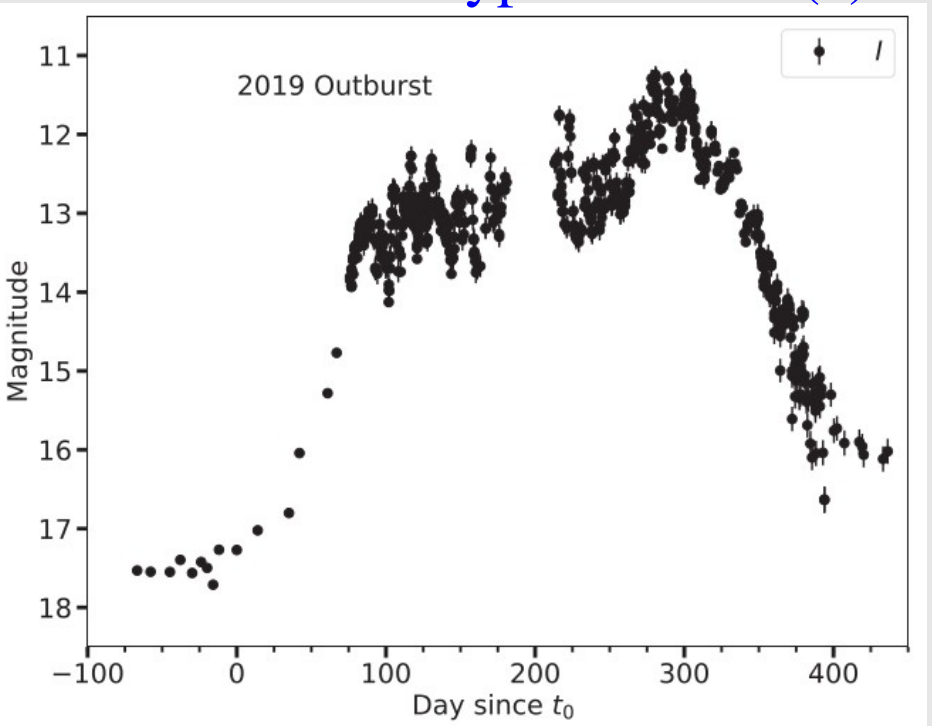
Can the WD in a CV produce the Z And-type outburst?

A candidate: The peculiar outburst in the classical nova binary V1047 Cen that appeared in 2019.

2005 Classical nova outburst



2019 Z And type outburst (?)



Left: Visual light curve of the 2005 classical nova eruption of V1047 Cen that is typical for fast novae. Progenitor: V > 20.5–21 → Δm > 12 mag + M_V > 5 before the 2005 outburst → main-sequence secondary, i.e. typical CV system.

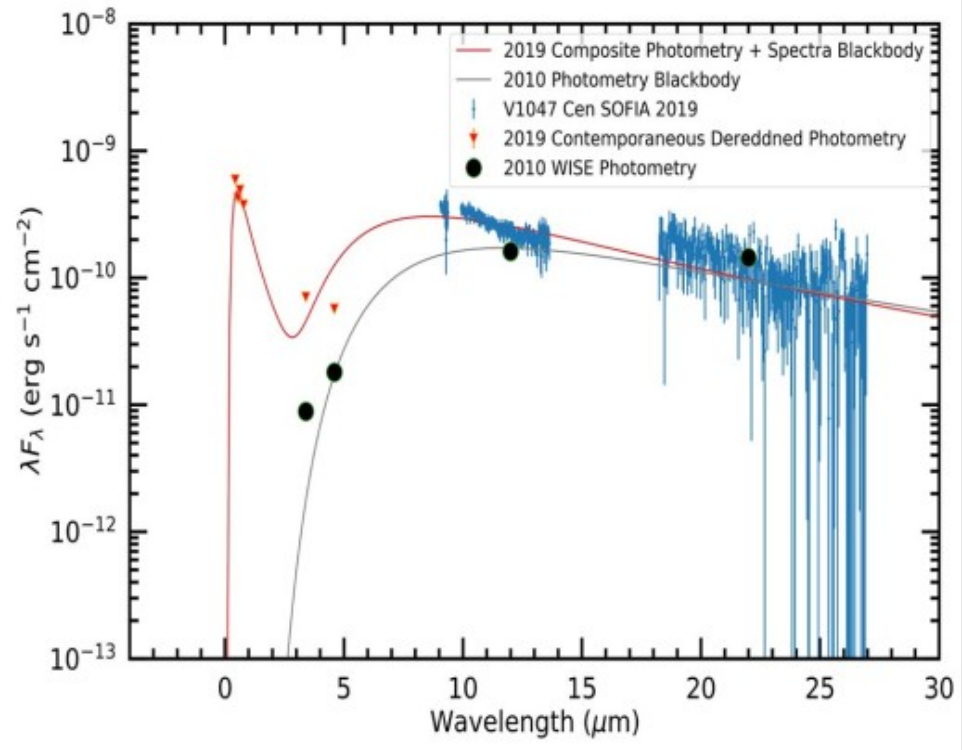
Right: The OGLE I-band light curve of the 2019 outburst of V1047 Cen. More energetic than a DN event. Possibly enhanced mass transfer leading to enhanced nuclear burning on the WD surface. Similarities with outbursts in symbiotic binaries.

(Figure and the results from Aydi et al. 2022, ApJ, 939:6)

V1047 Cen: The first Z And-type outburst observed in the classical nova binary

Aydi at al., (see 2022, ApJ, 939, 6):

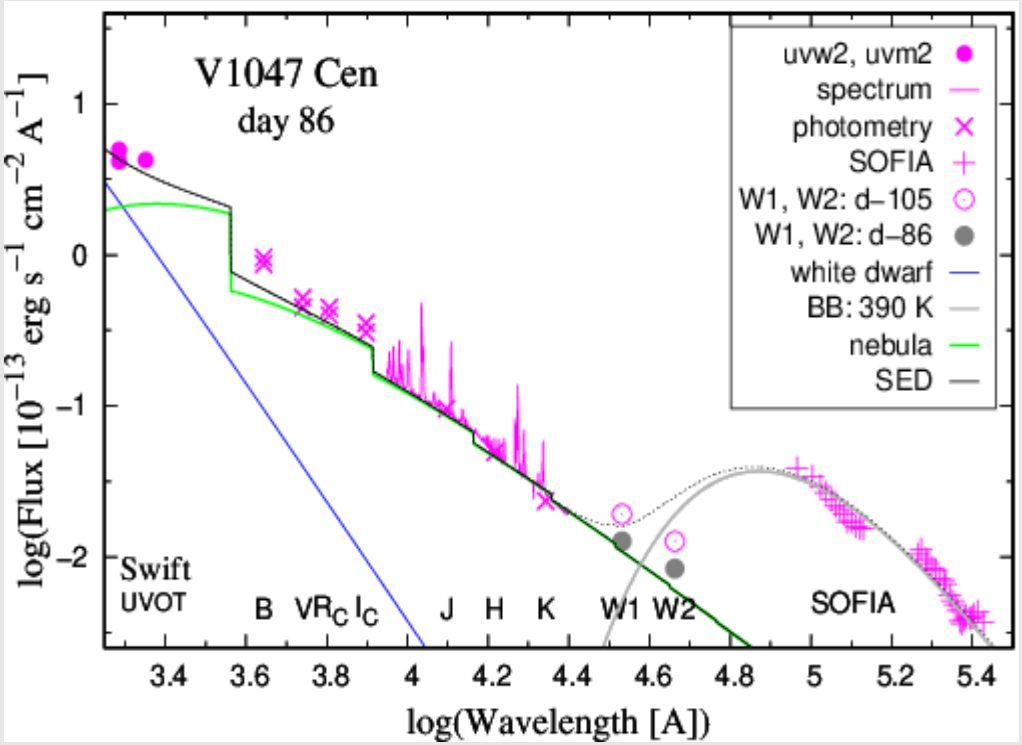
V1047 Cen: A Record Breaking Dwarf Nova Outburst or a New Phenomenon?



2 x BB:
AD ~6700 K + Dust ~400 K

Our analysis (see ApJ, 2025, 983:148):

V1047 Cen: The first Z And-type outburst observed in the classical nova binary

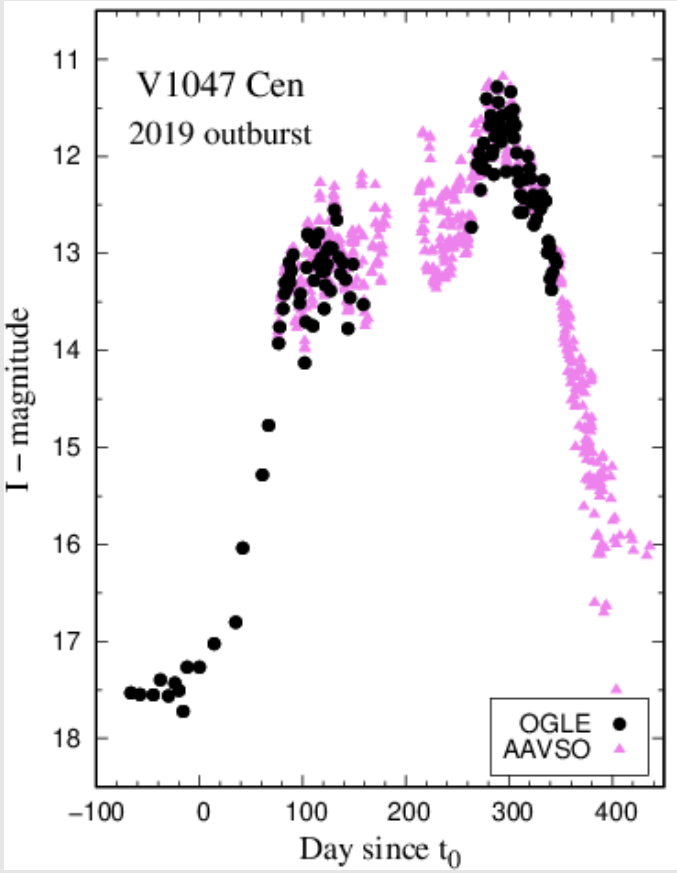


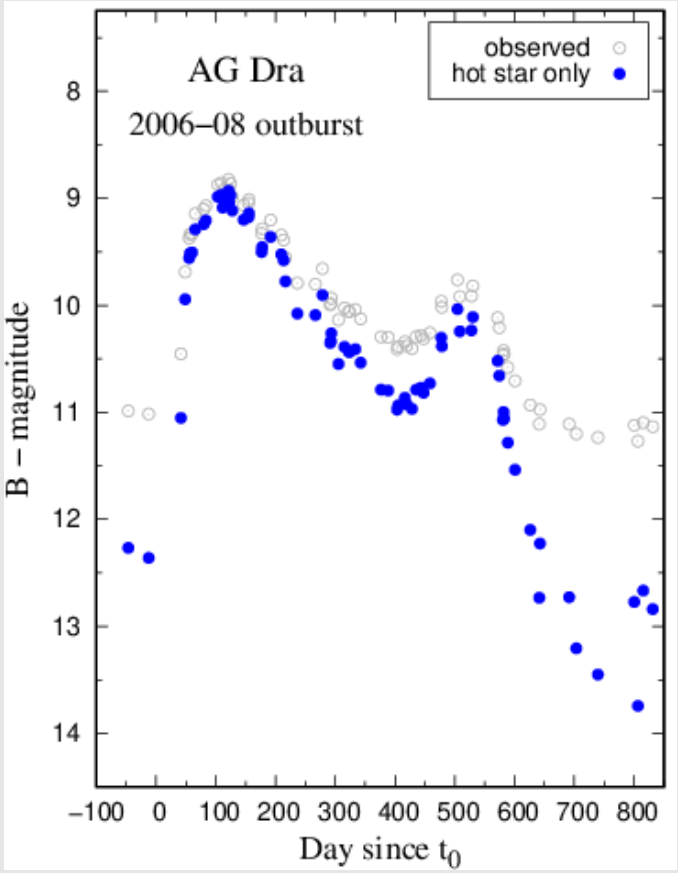
2 x BB: hot WD + Dust + Nebula
WD 1.5–2.0 x 10^5 K + Nebula + Dust

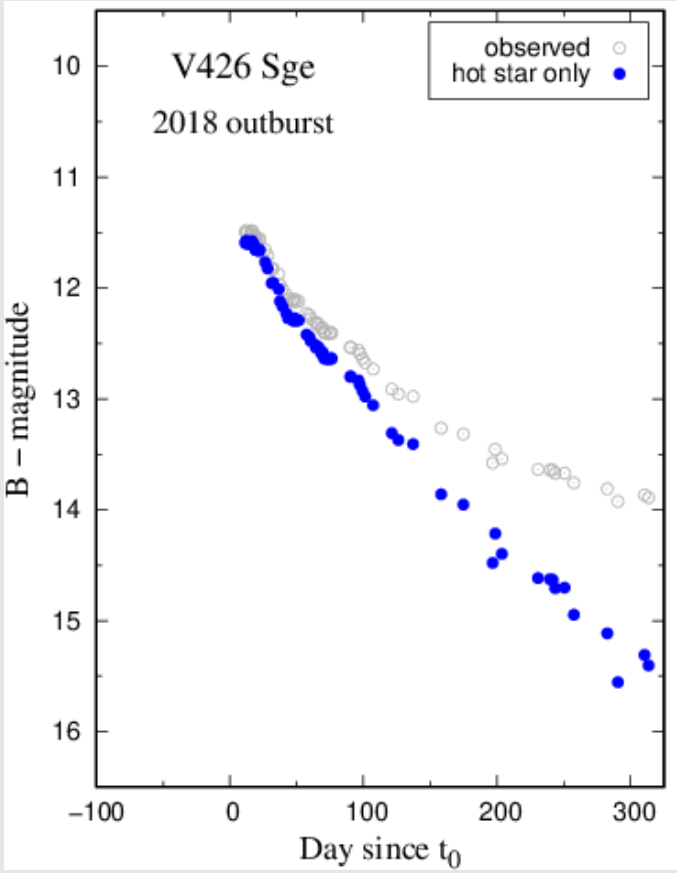
1. Photometric similarity

After removing the contribution from the giant, the amplitude of the brightness change for a typical Z And-type outburst can be around of 4 mag (here AG Dra, V426 Sge).

The slope of the brightening, the decrease in brightness and its amplitude, as well as the profile during the outburst (single or multiple maxima) are usually different for different SySts, but they can also be different for a given system.







2. Spectroscopic similarity

During outbursts of SySts, the emission profile of the hydrogen lines broadens considerably, with the wings extending up to +/- 1500 – 3000 km/s (bottom panels).
Broad wings are emitted by the fast ionized wind from the burning WD (dM/dt ~ 10^{-7} – 10^{-6} Mo/yr; $EM_{wind} \lesssim EM_{obs}$): → The ionized wind is responsible for the nebular emission (Skopal 2006, A&A, 457, 1003).

Aim: To prove the presence of strong nebular emission also for the classical nova V1047 Cen during its peculiar outburst in 2019.

Figure: Broad H-alpha profiles throughout the 2019 outburst of V1047 Cen (Aydi et al. 2022, ApJ, 939:6).

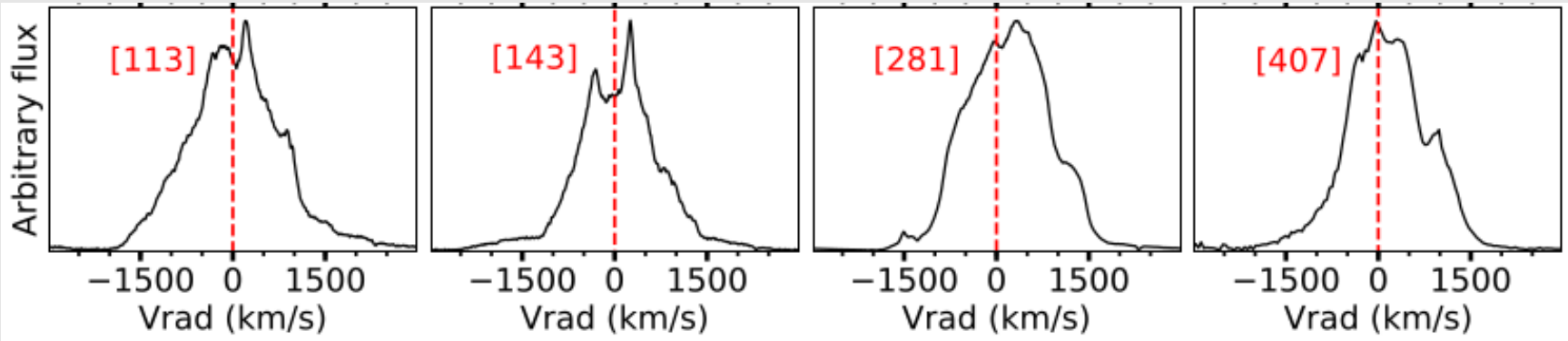
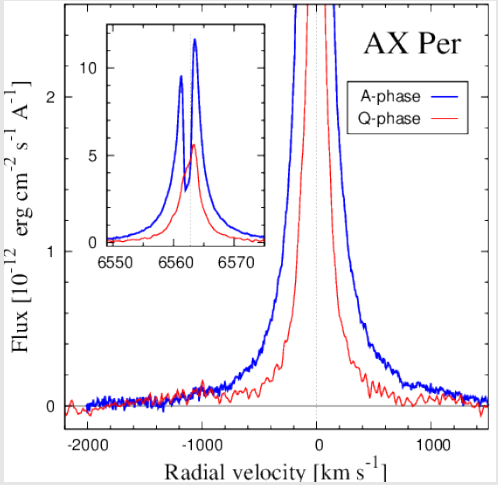
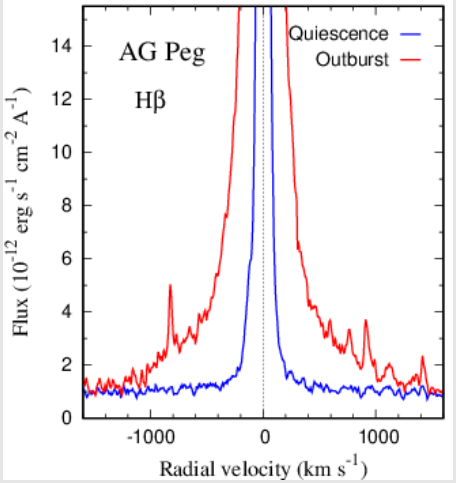
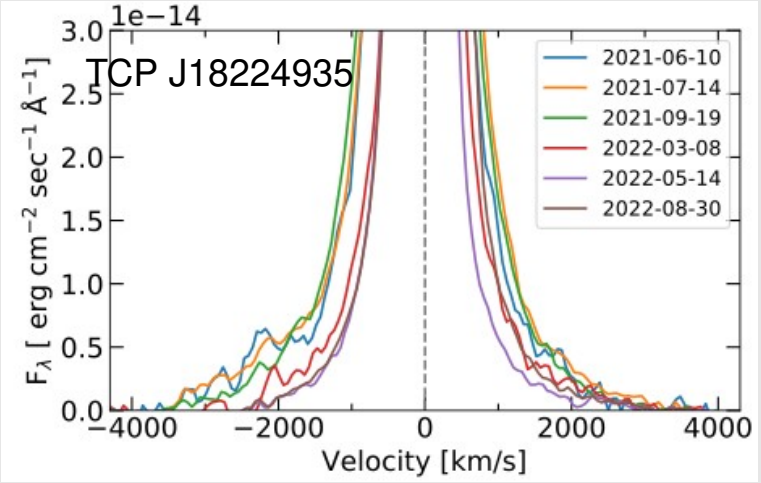


Figure: As above, but for outbursts of AX Per, AG Peg (Skopal et al. 2011, 2017) and TCP J18224935 (Sonith et al. 2023)







3. The spectral energy (SED) model

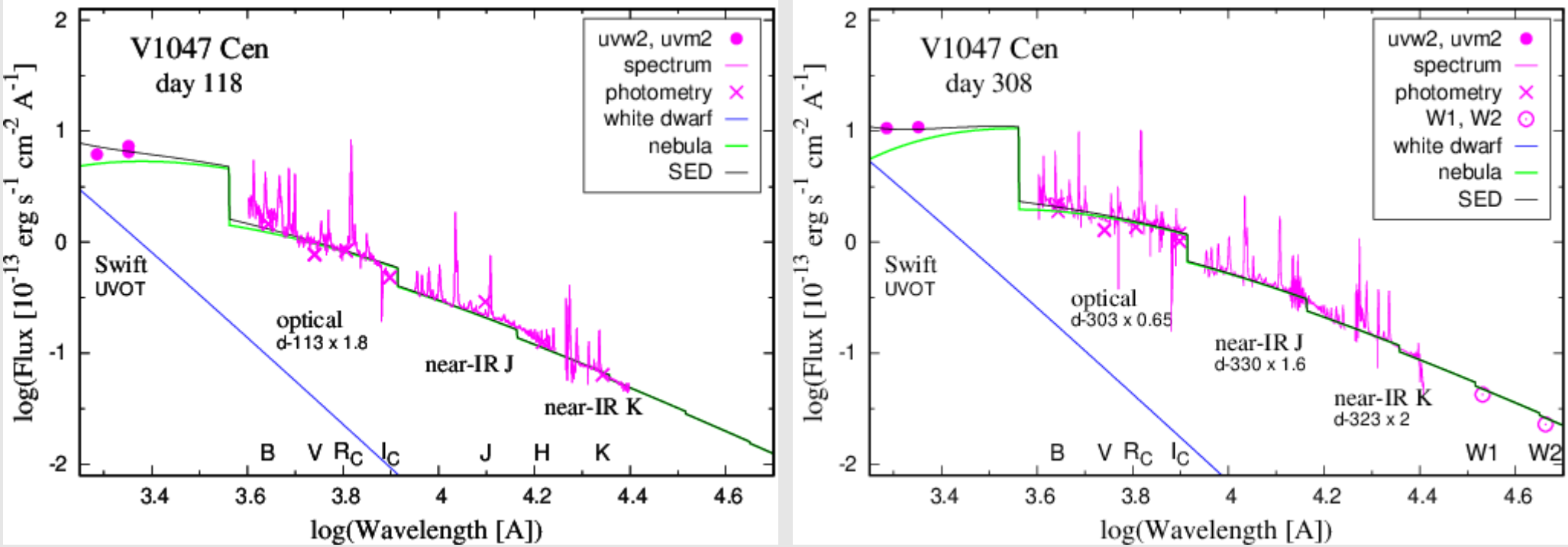
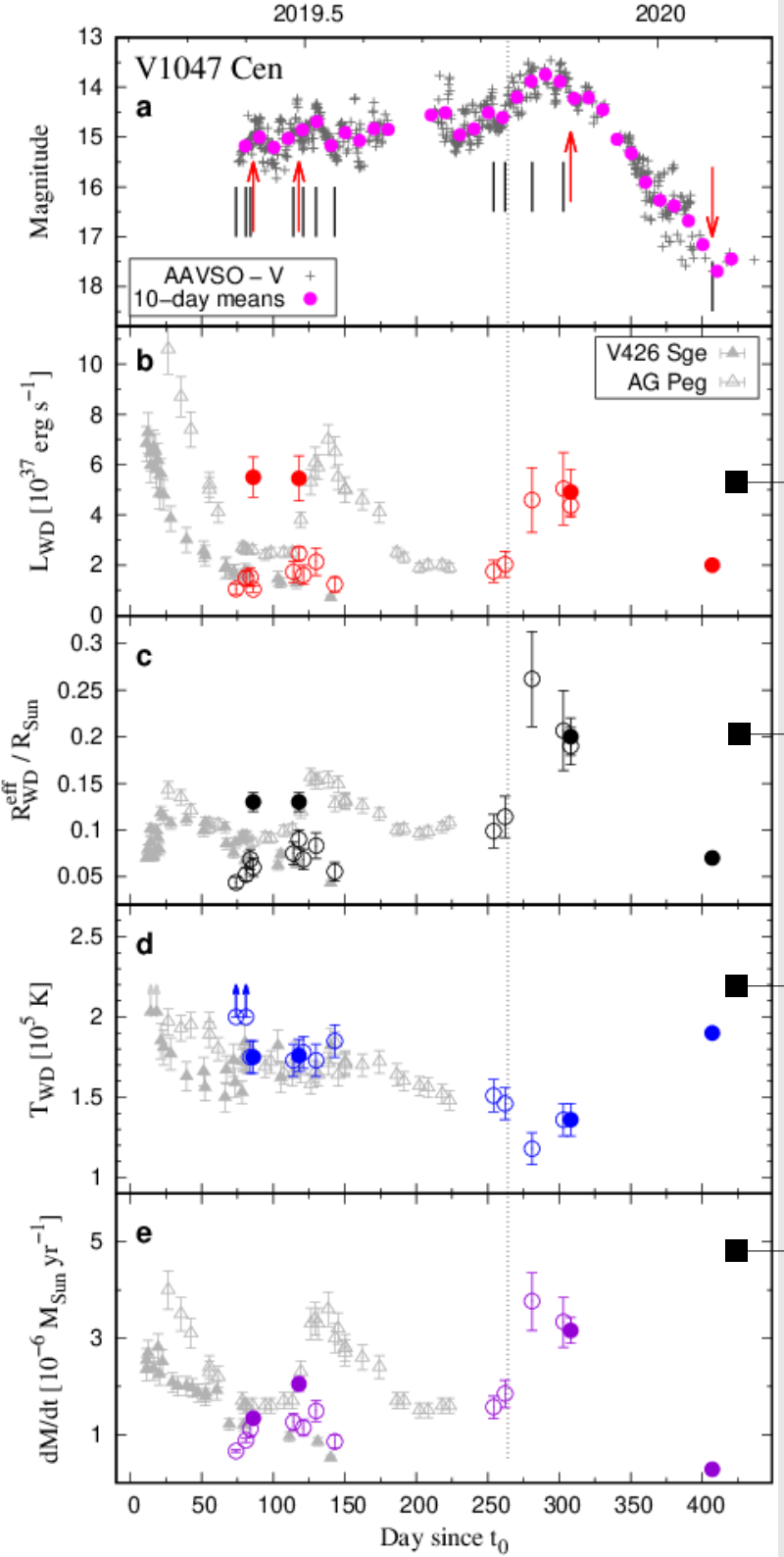


Figure: Observed (in magenta) and modeled (solid black line) spectral energy distribution (SED) of the classical nova V1047 Cen reconstructed for day 118 (left) and 308 (right) of its 2019 outburst. The model consists of a strong nebular continuum dominating the spectrum from near-UV to longer wavelengths, and a hot stellar source (the hot pseudophotosphere of the burning WD) rivaling the nebular continuum from the mid-UV to shorter wavelengths. *Left:* During the plateau phase, the ionizing source was as hot as 150–180 kK and the nebula was characterized with T_e ~ 30 000 K and EM ~ 1.4 x 10^{60} cm^{-3}.

Right: During the maximum, the ionizing source cooled to 110–130 kK, T_e decreased to ~ 20 000 K, while the EM increased to ~ 5 x 10^{60} cm^{-3}. Behavior of T_e is in agreement with that suggested by the color diagram analysis.

The SED models unambiguously confirm the presence of the strong nebular continuum in the spectrum of V1047 Cen during its 2019 outburst as generated during Z And-type outbursts of SySts.



Comparison of the physical parameters:

1. CV binary – V1047 Cen 2019 outburst
2. SySts – AG Peg and V426 Sge.

■ → L_{WD}(phot.) ~ a few x 10^{37} erg/s

■ → R_{WD}^{eff} ~ a few x 0.01–0.1 R_{Sun}

■ → T_{BB}(WD) ~ 1–2 x 10^5 K

■ → dM/dt(WD) = a few x 10^{-6} M_{Sun}/yr

Fundamental parameters and dM/dt during the 2019 V1047 Cen outburst are similar to those observed during the Z And type outbursts in SySts.

Conclusion

- Our analysis showed that after the nova explosion, the Z And-type outbursts can occur not only in SySts but also in short-period CVs.

- This result supports theoretical modeling that what appears after a nova explosion depends on the rate of accretion onto the WD, which resumes after the explosion.

- The presence of the Z And-type outburst in a CV indicates an extension of the nuclear burning time on the WD surface → faster evolution towards the supposed final stage of the SNe Ia explosion.

- We need to know the nature of the donor star and how a nova explosion can affect it.

Thank you for your attention