Possible connections of thermonuclear outbursts in accreting white dwarf binaries

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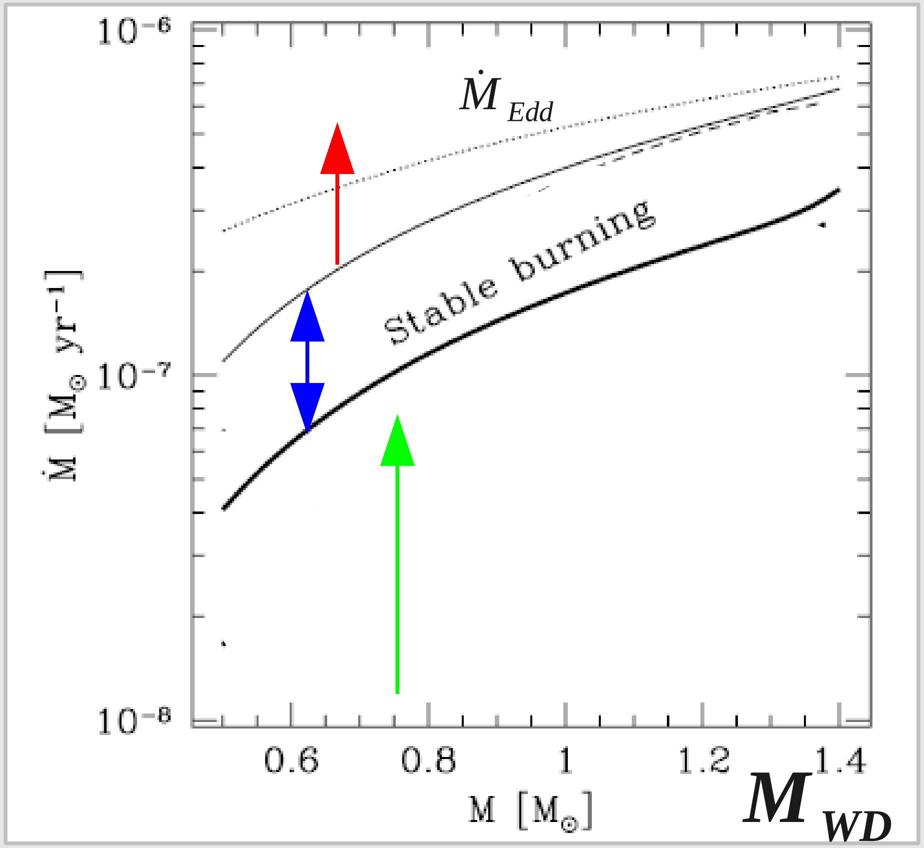
1. The response of a white dwarf (WD) to mass accretion
2. Observational manifestations of mass accretion onto WDs in symbiotic stars and cataclysmic variables
3. Summarization

Supported by the Slovak Academy of Sciences

VEGA grant No. 2/0030/21

Praha, June 6, 2024

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)

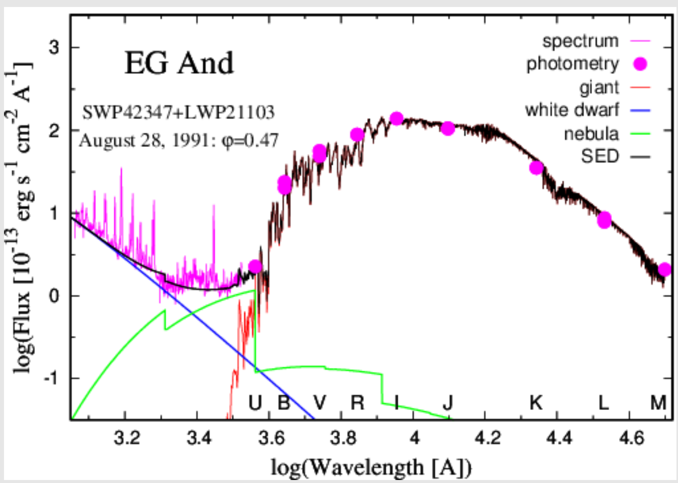
$$L_{WD} = L_{acc.} + L_{nucl.} = G\frac{M_{WD}\dot{M}_{acc}}{R_{WD}} + \eta X \dot{M}_{acc} \quad (\eta = 6.3\times10^{18}\,\mathrm{erg/g},\ \ X \equiv 0.7)$$

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

I.
Observational manifestations of mass accretion onto white dwarfs in symbiotic stars

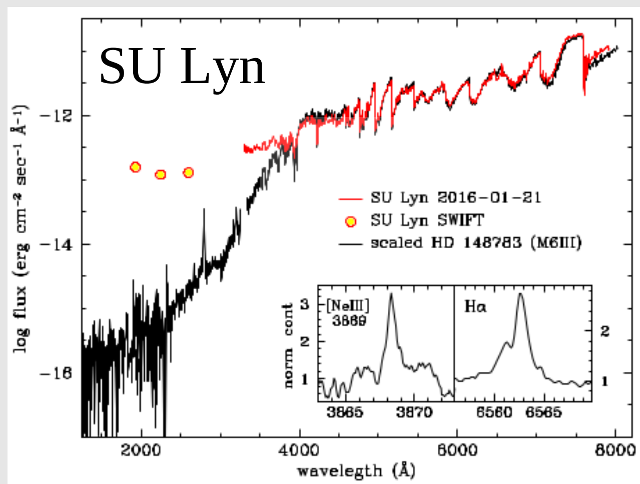
1. $\dot{M}_{acc} \prec \dot{M}_{stable}$ + $P_b \prec P_{crit}$: ***Accretion – powered*** (accreting-only) SySts
(e.g., EG And, SU Lyn, CQ Dra, hidden SySts)

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)



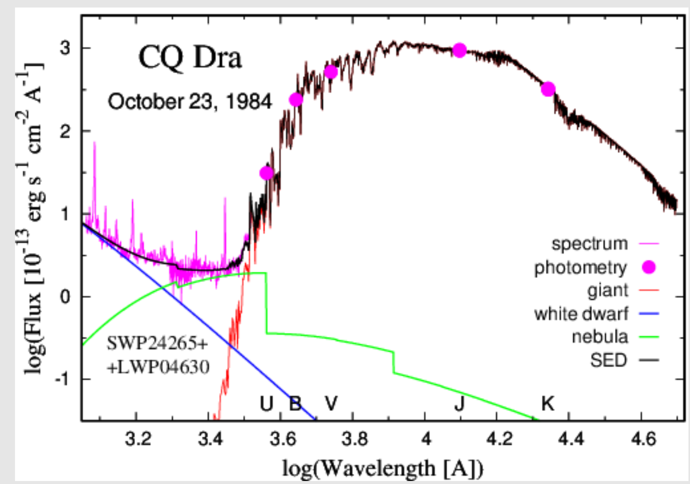
M3III + WD, $P_{orb} = 482\,d$, eclipses,
$L \sim 2.5\times10^{35}(d/590\,pc)^2$ erg/s,
orbital-related var. of the opt. em. l.

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,
$L_{UV} \sim 1\times10^{34}(d/640\,pc)^2$ 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



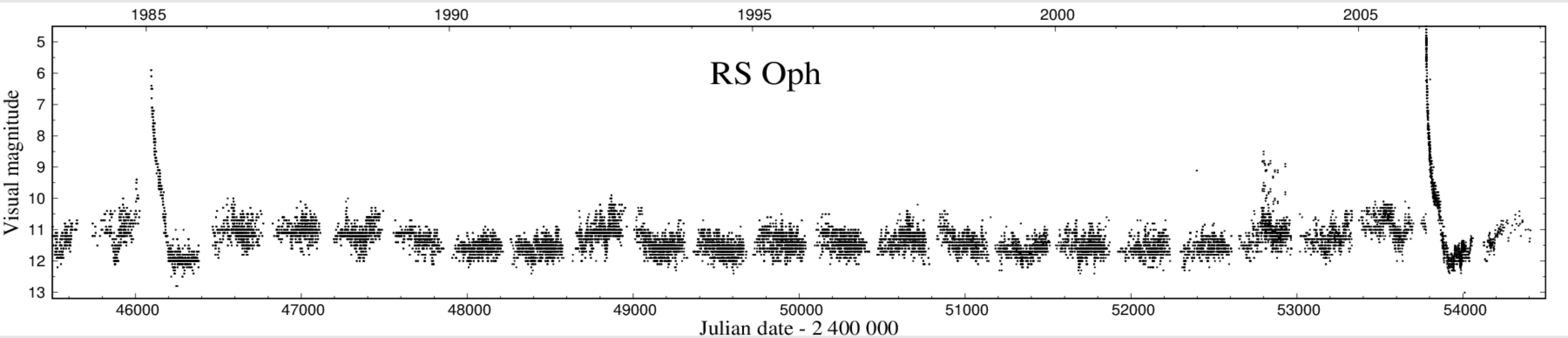
M3III + WD, $P_{orb} = 1703\,d$,
$L \sim 2.5\times10^{34}(d/178\,pc)^2$ erg/s,
variable nebular continuum.

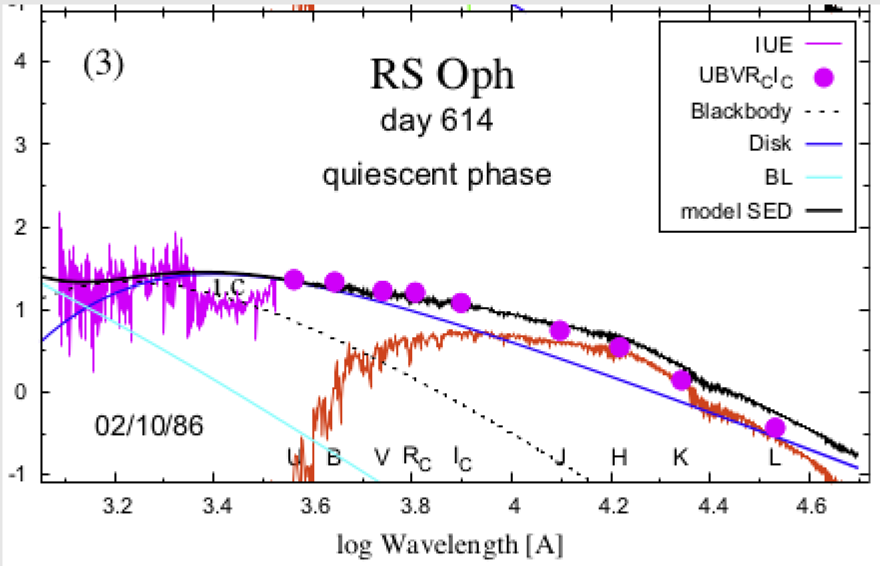
Reimers, D. 1985, A&A, 142, L16;
Wheatley et al. 2003, MNRAS, 346, 855;
Skopal, A. 2005, ASP Conf. Ser. 330, 463;
– 2005, A&A, 440, 995;

2. $\dot{M}_{acc} \prec \dot{M}_{stable}$ + $P_b = P_{crit} \rightarrow$ ***nova outbursts*****:** (recurrent) symbiotic novae.

(a) Post-outburst evolution at $\dot{M}_{acc} \prec \dot{M}_{stable}$: usually, recurrent SyNe with $\uparrow M_{WD}$.

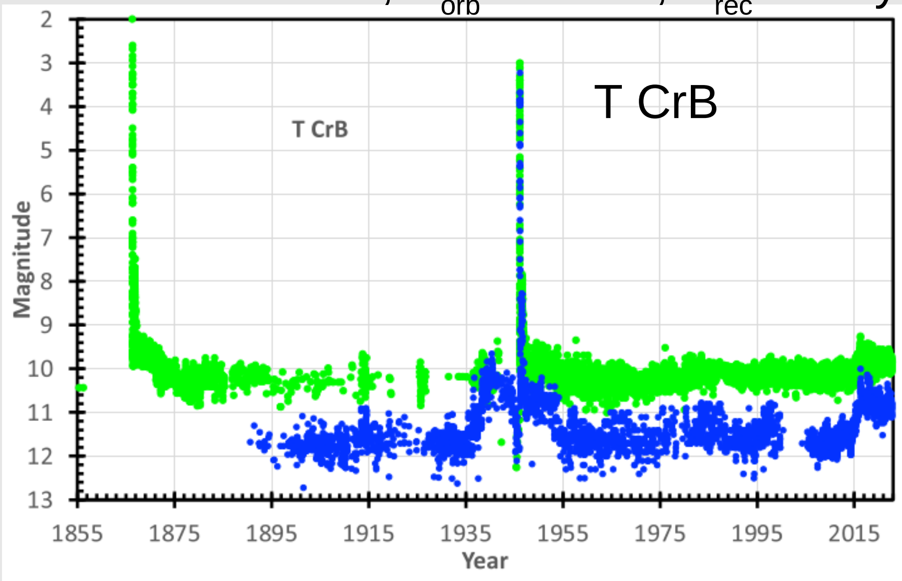
RS Oph: K7III + WD, P_{orb} = 455 d, P_{rec} ~ 15-20 years; Figure: Visual LC from AAVSO





Model SED for RS Oph during quiescence.
dM/dt ~ 5 x 10^{-8} M_{sun}/yr, L_{AD} ~ 360 L_{sun}
(Skopal, 2015, NewA, 34, 123)

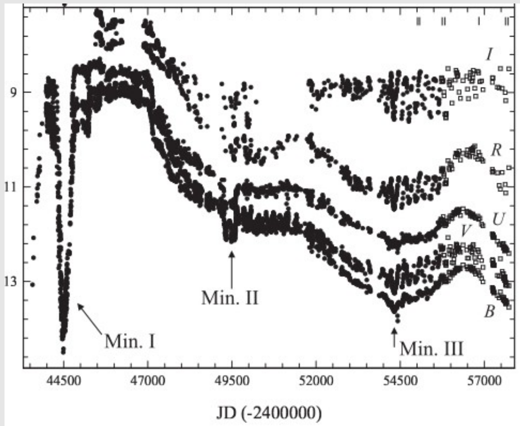
T CrB: M4III + WD, P_{orb} = 228 d, P_{rec} ~ 80 yr

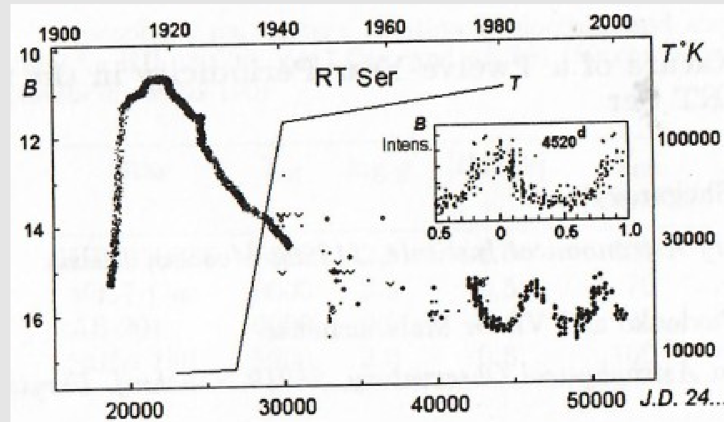


V (green) and B (blue) light curves of T CrB covering eruptions in 1866 and 1946.
(Schaefer, 2023, MNRAS, 524, 3146)

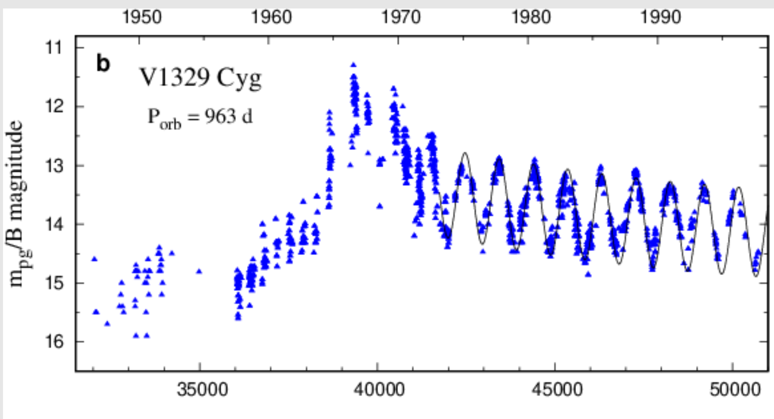
(b) Post-outburst evolution at $\dot{M}_{acc} \sim \dot{M}_{stable}$: ***Nuclear – powered*** (shell-burning) SySts:
L = a few x $10^3 L_{Sun}$, wave-like orbital-related variability (if known, $M_{WD} < 1\, M_{Sun}$).

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)



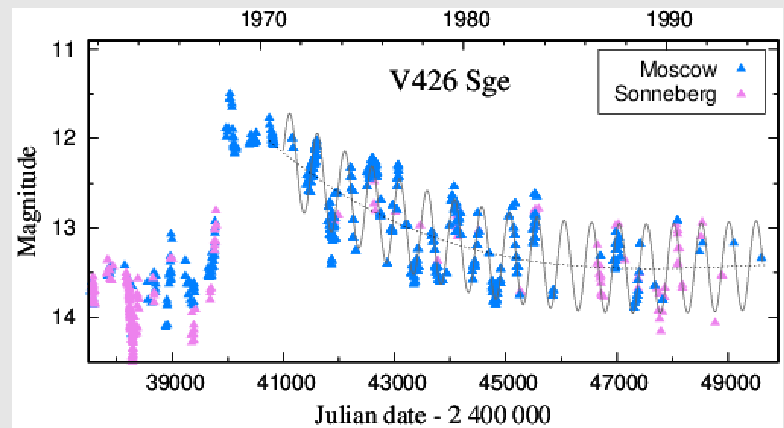


RT Ser:
M5.5III + WD
P_{orb} = 4431 d
Post-outburst:
L_{WD} ~ 3300 L_{solar}
(Shugarov et al. 2003; Muerset & Nussbaumer, 1994)



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)

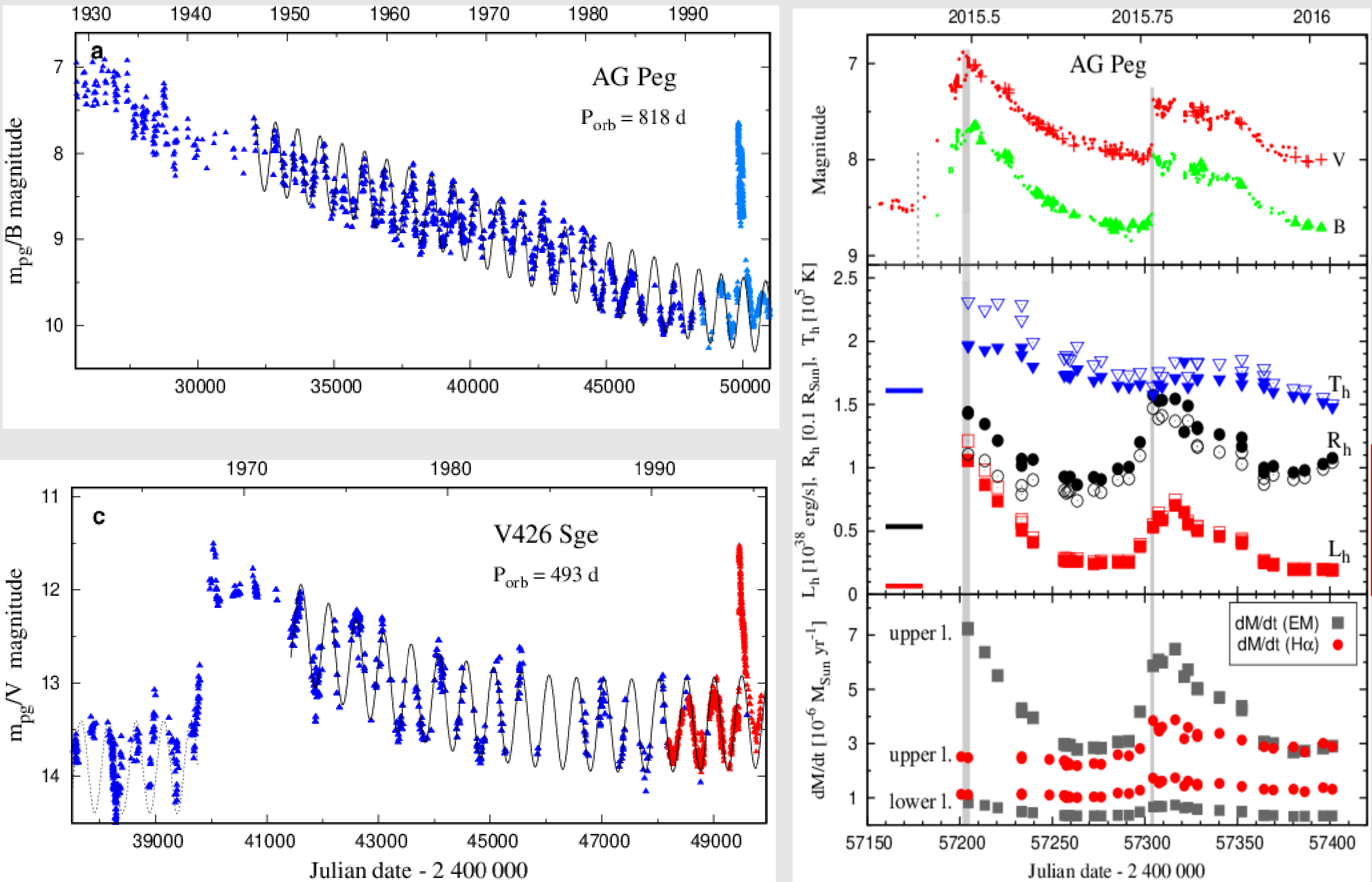


V426 Sge: M4.8III + WD, P_{orb} = 494 d,
Nova outburst in 1968, non-eclipsing,
Post-outburst: L_{WD} ~ 2000 L_{solar}, EM ~ 10^{59-60} cm^{-3}, T_{BB} ~ 150 kK, R_{WD} ~ 0.07 R_{solar}.

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

3. $\dot{M}_{acc} > \dot{M}_{stable}$: **Z And−*type outbursts*** due to a transient increase in $\dot{M}_{acc}$:

(a) short-lasting $\uparrow \dot{M}_{acc} \rightarrow$ short-lived (weeks/months) outbursts
(e.g., LT Del, AG Peg, V426 Sge,...)



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).

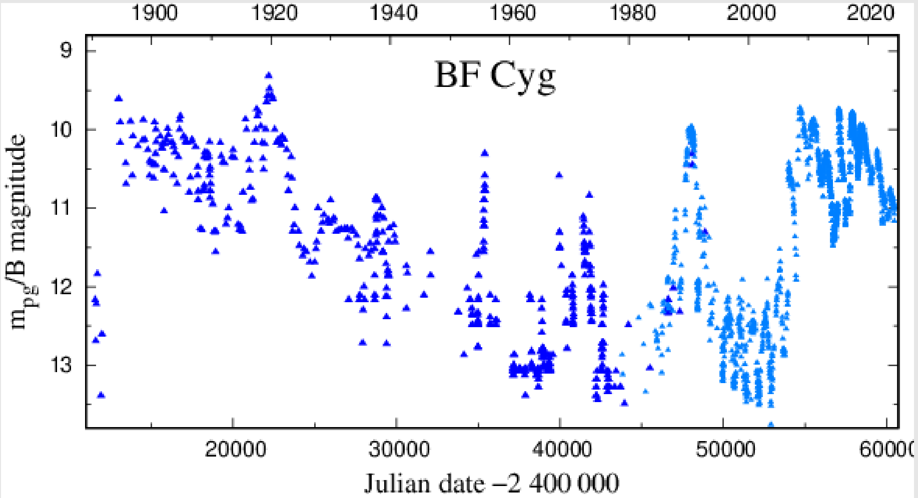
What ignites the outburst?
(i) A disruption of the AD → infall of H-rich material onto the WD.
(ii) Variation in the mass-transfer from the red giant.

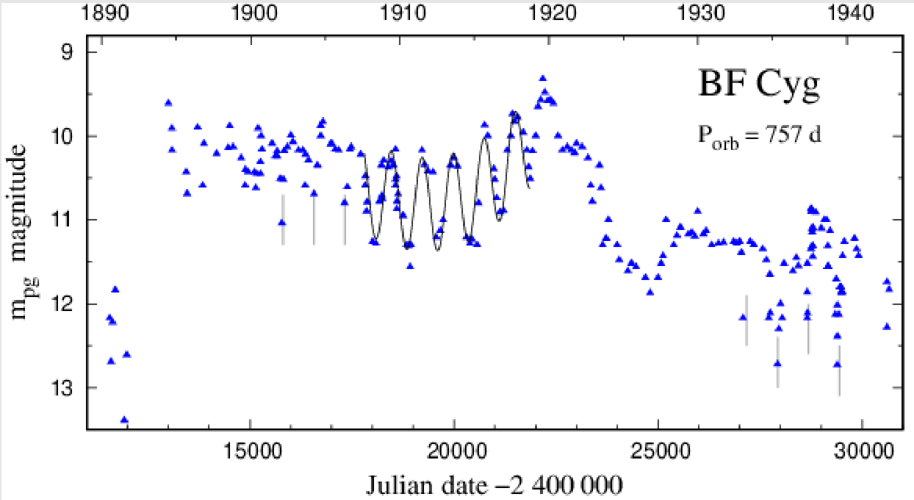
(Sokoloski et al. 2006; Bisikalo et al. 2006)

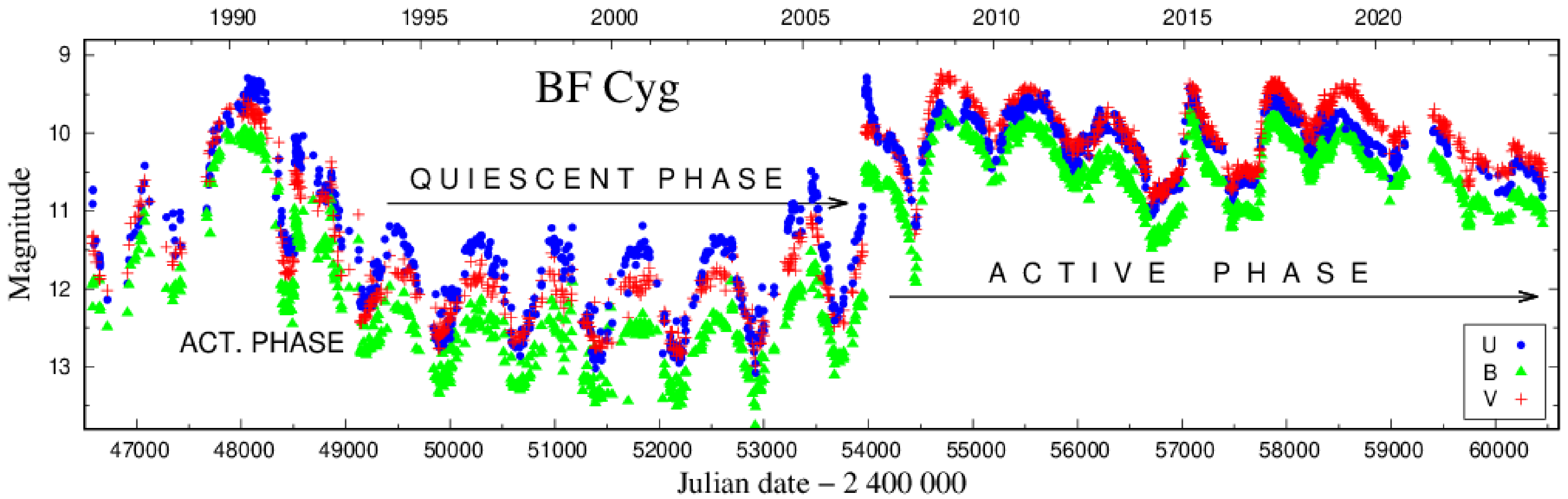
Figure. *Left:* Transition from the symbiotic nova outburst to quiescence and to Z And-type outburst for AG Peg (top) and V426 Sge (bottom). *Right:* LC and L, R, T, and dM/dt parameters for AG Peg during its 2015 outburst (Skopal et al. 2017, 2020).

(b) long-lasting ↑ $\dot{M}_{acc}$ → long-lived (years/decades) outbursts (e.g., Z And, BF Cyg 2006-present)

BF Cyg: M5.5III+WD, P_{orb} = 757 d, nova-outburst in 1894 + (long-lasting) Z And-type outbursts







Wave-like orbital-related variation signals L_{WD} **~ a few × 10**^{36} erg/s, $(EM \sim 10^{59} - 10^{60}\,\mathrm{cm}^{-3})$, which requires $\dot{M}_{acc} \sim \dot{M}_{stable}$.

II.
Observational manifestations of mass accretion onto white dwarfs in cataclysmic variables

Are there observational counterparts to SySts for $\dot{M}_{acc} \succ \dot{M}_{stable}$ and $\dot{M}_{acc} \sim \dot{M}_{stable}$?

1. $\dot{M}_{acc} \succ \dot{M}_{stable}$ for a long time → supersoft X-ray sources with $L \sim 10^{38} - 10^{39}$ erg/s :

CAL 83: Prototypical SSS, P_{orb} ~1 d, high F_{4686}/F_{beta} ,
mass-outflow ~2300 km/s; X-ray-off/on → optical-high/low

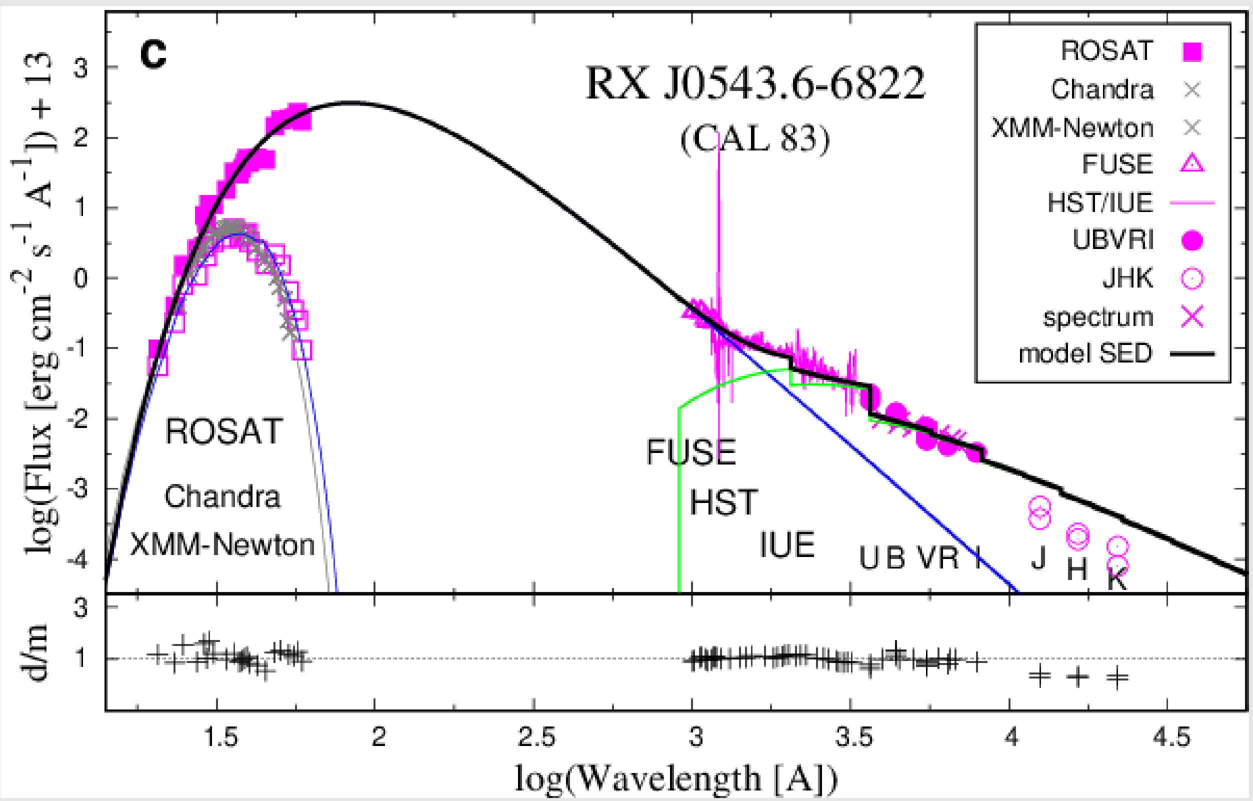


Figure and results adapted according to Skopal, 2022, AJ 164:145

The model SED from supersoft X-rays to near-IR:

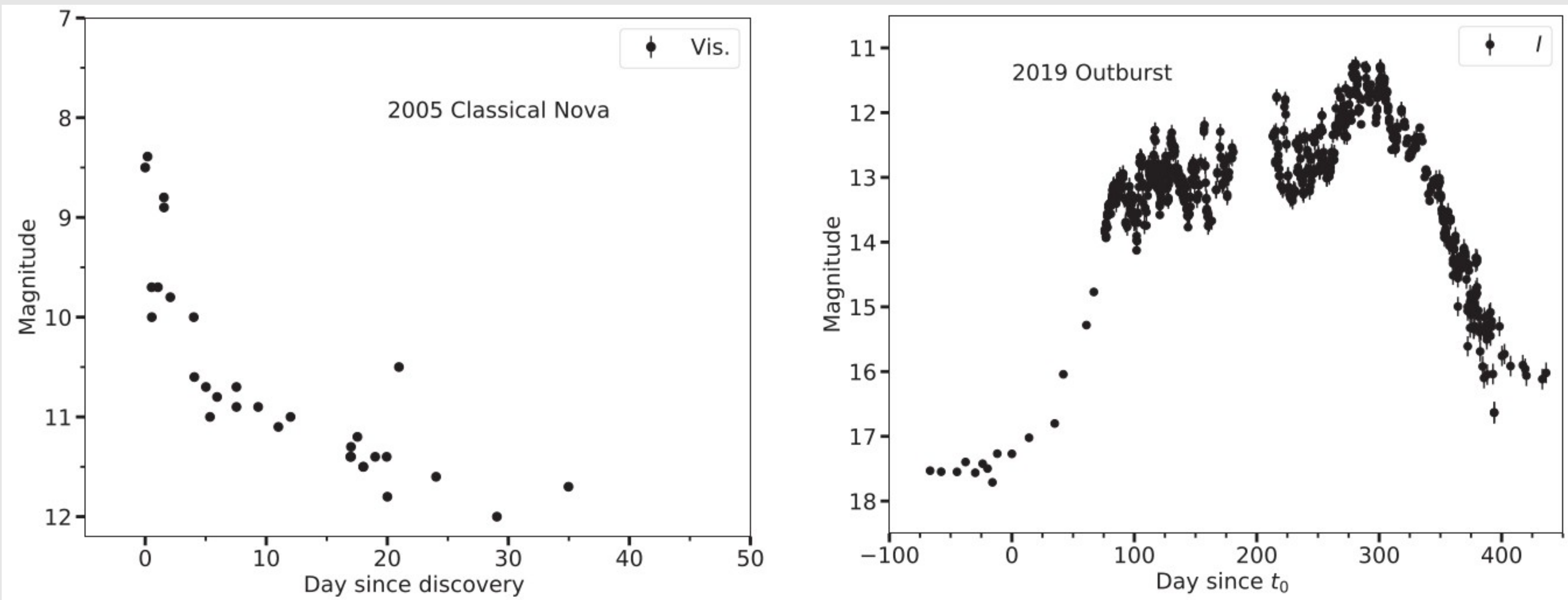
$L_{SSS} \sim 1.1\, x\, 10^{39}$ erg/s, $T_{BB} = 350$ kK
$R_{WD} = 0.15\, R_{Sun}$, $N_H \sim 1 \times 10^{21}\,\mathrm{cm}^{-2}$
$EM = 2.9 \times 10^{60}\,\mathrm{cm}^{-3}$, $T_e = 30{,}000$ K ,
$\dot{M}_{wind} \gtrsim 10^{-6}\, M_{Sun}/yr$

The brightest SSSs could be unidentified optical novae in a post-nova SSS state sustained at a high long-lasting luminosity by resumed accretion at super-Eddington rates.

(high accretion rate after nova outburst – Kovetz et al. 1988; long SSS phase - Kato et al. 2017)

2. $\dot{M}_{acc} \succ \dot{M}_{stable}$ for a short time → **Z And-type outburst** in classical nova binary

Example: the 2019 outburst of the classical nova V1047 Cen:



Left: Visual light curve of the 2005 classical Nova outburst 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.

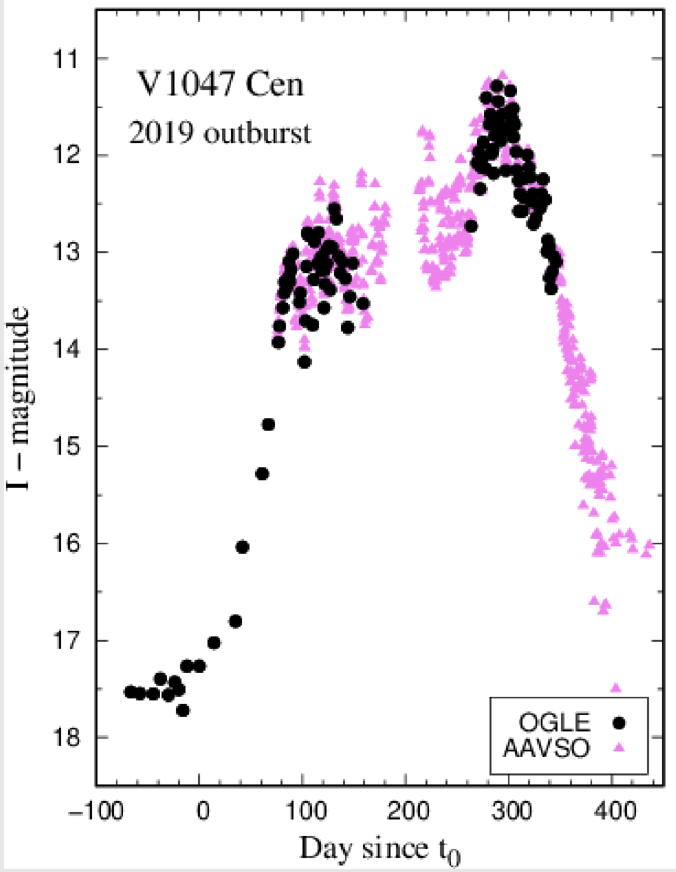
Right: The OGLE I-band light curve of the 2019 outburst of V1047 Cen. More energetic than a DN event. Possibly enhanced mass transfer leading to enhanced nuclear burning on the WD surface. Similarities with outbursts in symbiotic binaries.

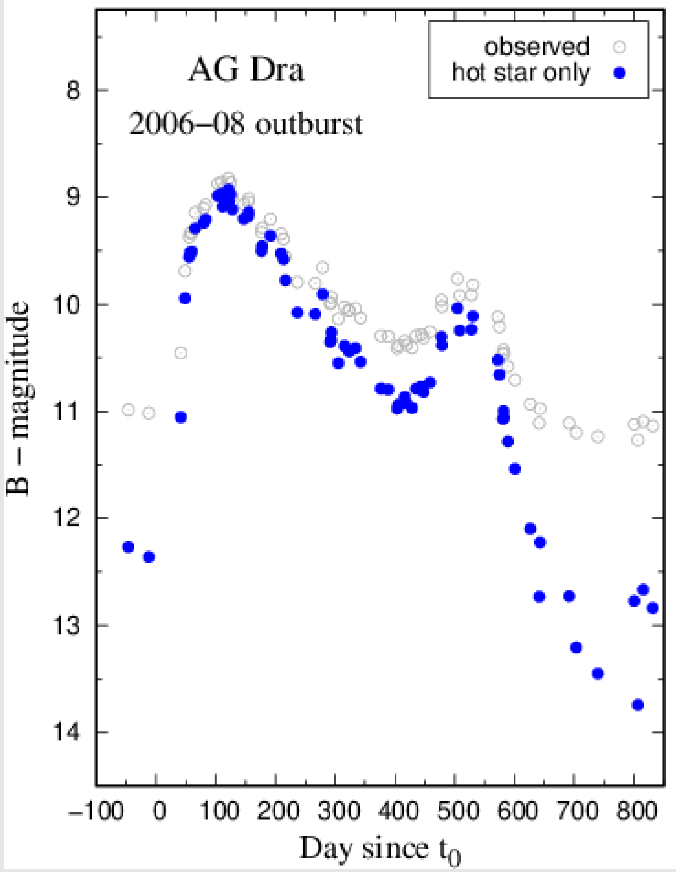
(Figure and the results from Aydi et al. 2022, ApJ, 939:6)

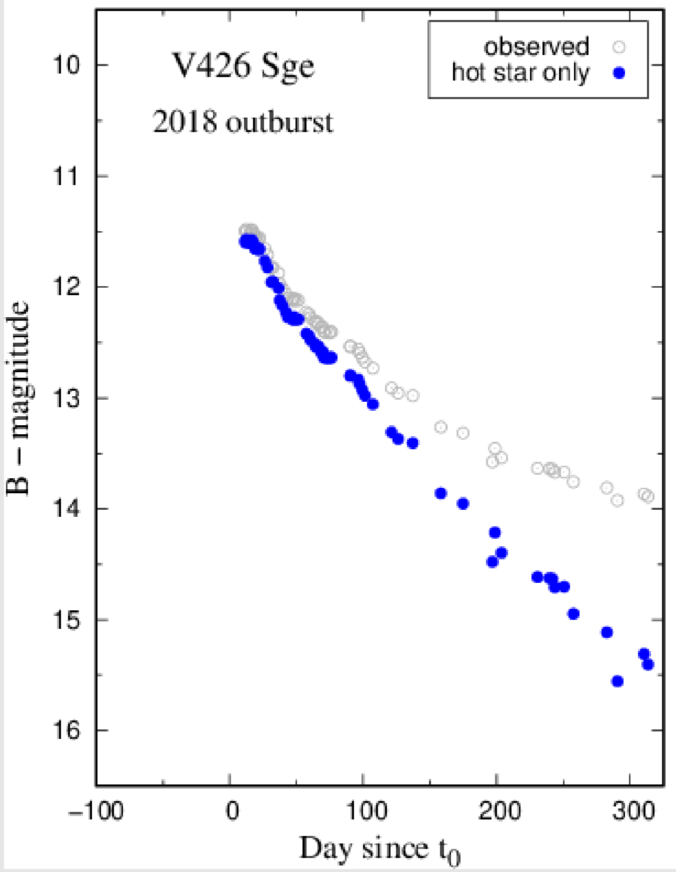
Photometric similarity

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.







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

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

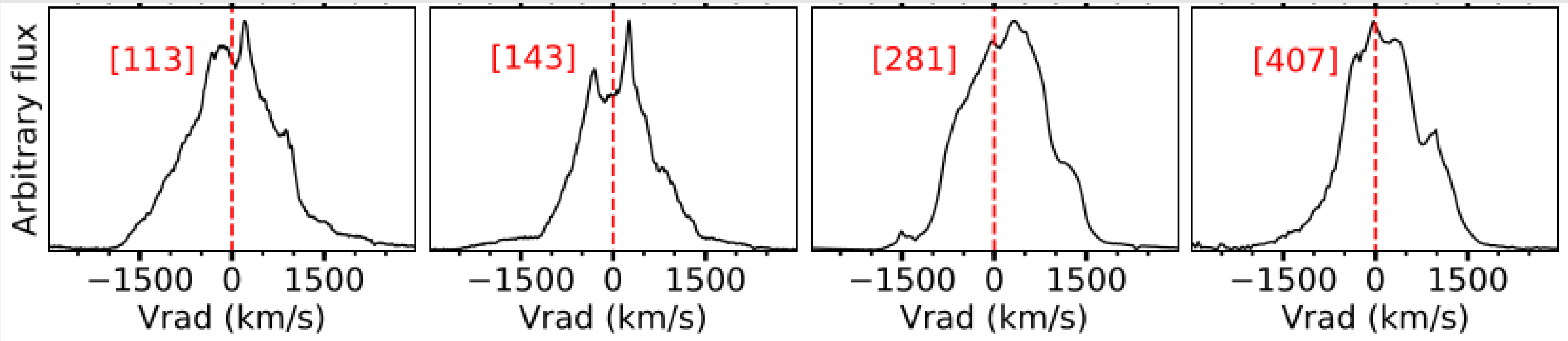
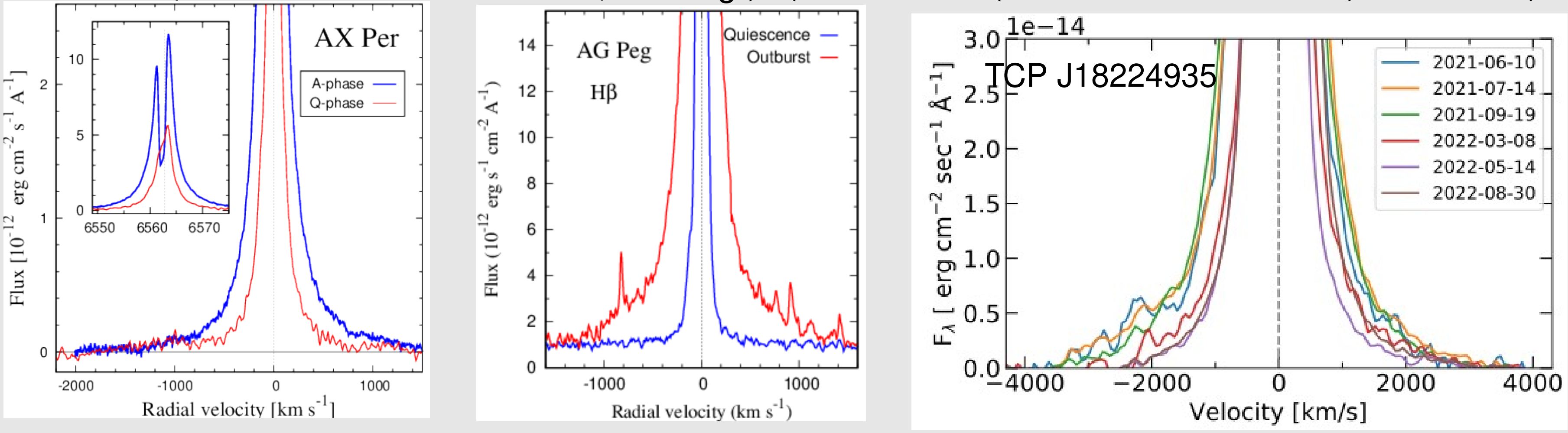


Figure: As above, but for outbursts of AX Per, AG Peg (Skopal et al. 2011, 2017) and TCP J18224935 (Sonith et al. 2023)



Conclusions

1. Observations suggest that different types of thermonuclear outbursts on the WD surface can occur in both SySts and CVs.

2. Observations confirm theoretical modeling that what appears after a nova explosion depends on the rate of accretion onto the WD, which resumes after the explosion (e.g. Shara et al. 1986; Kovetz et al. 1988; Kato et al. 2017)

Symbiotic Stars	Cataclysmic Variables
1. $\dot{M}_{acc} \prec \dot{M}_{stable}$: ***Accretion – powered*** (accreting-only) SySts (e.g., EG And, SU Lyn, hidden SySts)	Quiet Cataclysmic Variables
2. $\dot{M}_{acc} \sim \dot{M}_{stable}$: ***Nuclear – powered*** (shell-burning) SySts (quiescent SySts, e.g., Sy Mus, RW Hya) (Q-phases of, e.g., AG Dra, Z And, BF Cyg)	V1047 Cen: between the 2005 and 2019 outbursts, and after the 2019 outburst
3. $\dot{M}_{acc} > \dot{M}_{stable}$: **Z And – *type outbursts***	
- short-lasting $\uparrow \dot{M}_{acc} \rightarrow$ short-lived outbursts (e.g., LT Del, AG Dra, V426 Sge, AG Peg)	2019 outburst of V1047 Cen
- long-lasting $\uparrow \dot{M}_{acc} \rightarrow$ long-lived outbursts (e.g., Z And, BF Cyg 2006-present)	Luminous supersoft X-ray sources in LMC and SMC

Thank you for your attention