Mystery of the classical nova V339 Del: Long-lasting Super-Eddington Luminosity with Dust Emission

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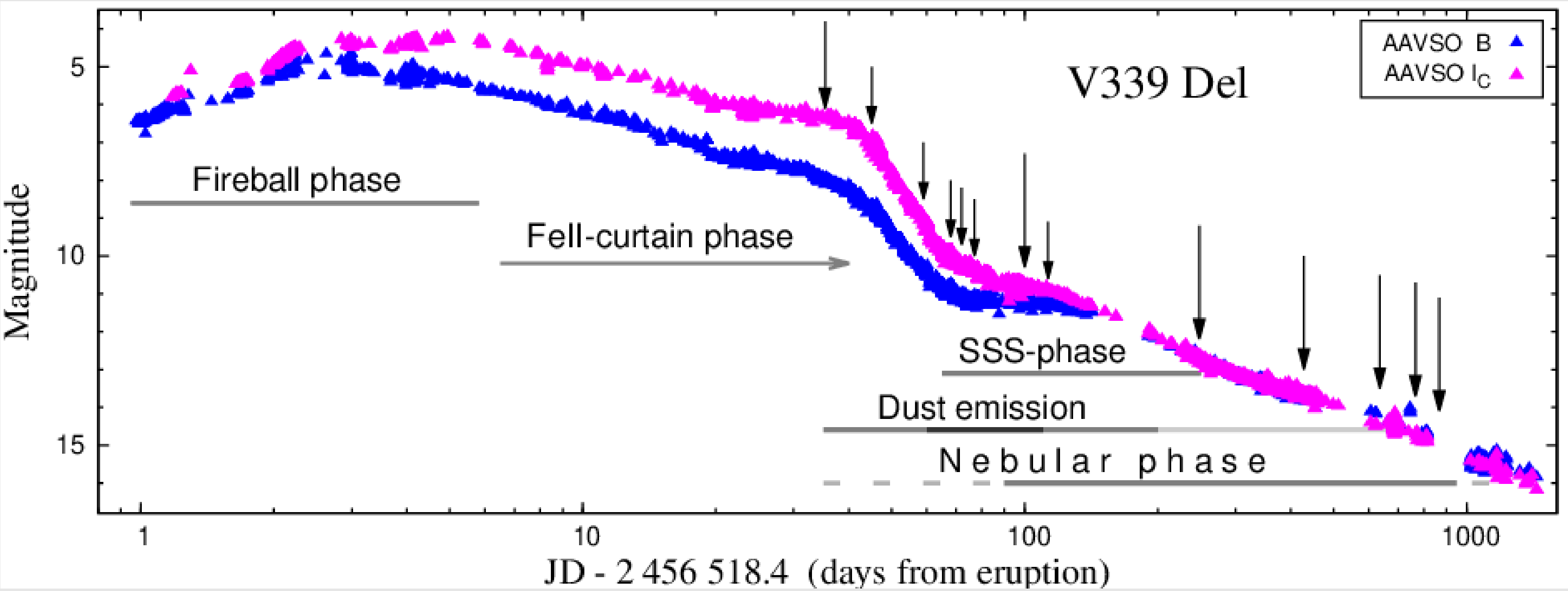
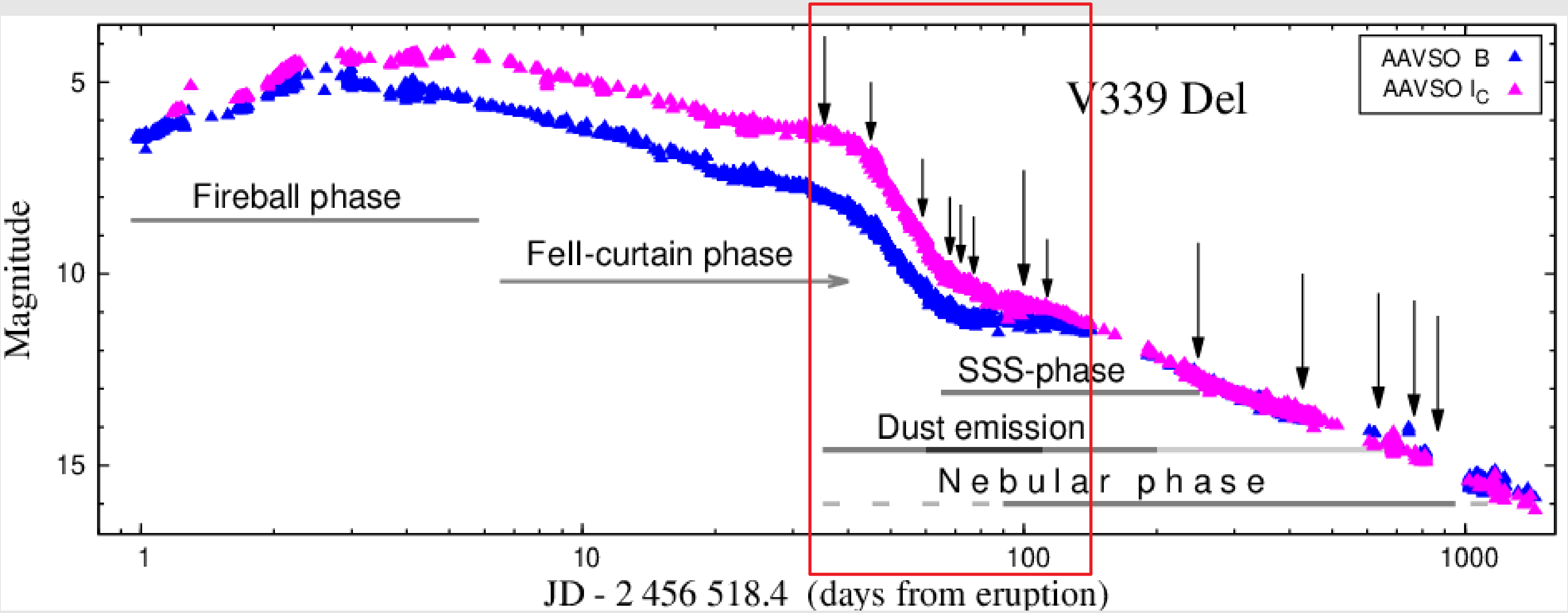
1. Classical nova V339 Del (Nova Delphini 2013)
2. Age 35 days: Oblate shape of the WD & creation of dust
3. Transition (35 – 72): Wind stopping-down
4. Age 100 days: Super-Eddington luminosity with dust
5. Conclusions

Evolution of B and I_C light curves



Explosion:	August 13.9, 2013
Day of discovery:	August 14.584, 2013
Fireball phase:	August 14.8 – 19.9, 2013
FeII-curtain phase:	August 21.7 – Sept. 18, 2013
X-ray emission:	Sept. 18, 2013 – April, 2014
SSS-phase:	October 18. 2013 – April, 2014
Dust emission:	Sept. 17, 2013 – May, 2015

Evolution of B and I_C light curves



<u>Transition to super-soft X-ray phase</u>

Day 35 to day 100 of the nova life

(i) Day-35 SED model, (ii) 3-4 mag decline, (iii) day-100 SED model

Modelling the SED of novae during **transition to super-soft X-ray phase**

White dwarf Nebula Dust

$$F(\lambda) = \theta_{WD}^2 \pi B_\lambda(T_{BB}) \exp[-\sigma_{Ray}(\lambda) N_H] + k_N \times \epsilon(\lambda, T_e) + \theta_D^2 \pi B_\lambda(T_D)$$

fitting parameters: $\theta_{WD},\ T_{BB},\ k_N,\ T_e,\ \theta_D,\ T_D$

$\theta_{WD} = \frac{R_{WD}^{eff}}{d}$ – *angular radius of the WD pseudophotosphere*

$\sigma_{Ray}(\lambda)$ – *Rayleigh scattering cross-section*

N_H – *ISM + CSM column density of* H^0

k_N – *observed emission measure*

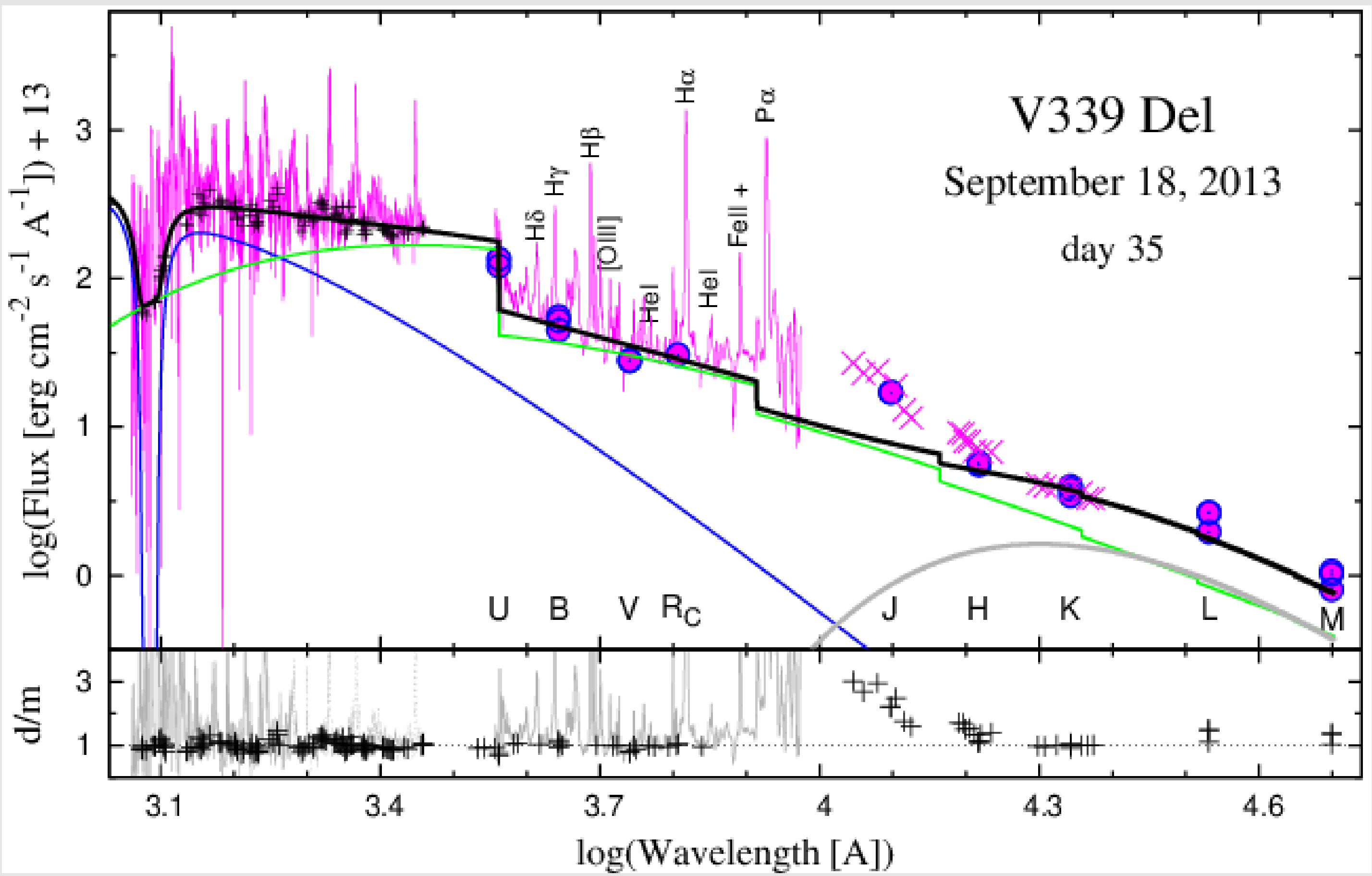
T_e – *electron temperature*

$$R_{WD}^{eff} = \theta_{WD} \times d, \quad L_{WD} = 4\pi d^2 \theta_{WD}^2 \sigma T_{BB}^4, \quad EM = 4\pi d^2 \times k_N$$

Day-35: September 18, 2013: UV – IR SED

WD: T_{BB} ~ 31000 K, R_{WD}^{eff} ~ 5.9 R_{sun}, L_{WD} ~ 30000 L_{sun}, $N_H = 1.1\text{x}10^{23}$ cm^{-2}.
Nebula: T_e ~ 26000 K, EM = 1.9 × 10^{62} cm^{-3}. Dust: T_D ~ 1450 K, L_D ~ 3100 L_{Sun}

$$L_H(\mathrm{WD}) \ll \alpha_B \times EM \rightarrow \text{oblate shape of the WD phot.}$$



Modelling the SED of novae during **super-soft X-ray phase**

White dwarf Nebula Dust

$$F(\lambda) = \theta_{WD}^2 \pi B_\lambda(T_{BB}) \exp[-\sigma_X(\lambda) N_H] + k_N \times \epsilon(\lambda, T_e) + \theta_D^2 \pi B_\lambda(T_D)$$

fitting parameters: $\theta_{WD},\ T_{BB},\ k_N,\ T_e,\ \theta_D,\ T_D$

$\theta_{WD} = \dfrac{R_{WD}^{eff}}{d}$ – *angular radius of the WD pseudophotosphere*

$\sigma_X(\lambda)$ – *total cross-section for photoelectric absorption per H atom*

N_H – *ISM + CSM column density of* H^0

k_N – *observed emission measure*

T_e – *electron temperature*

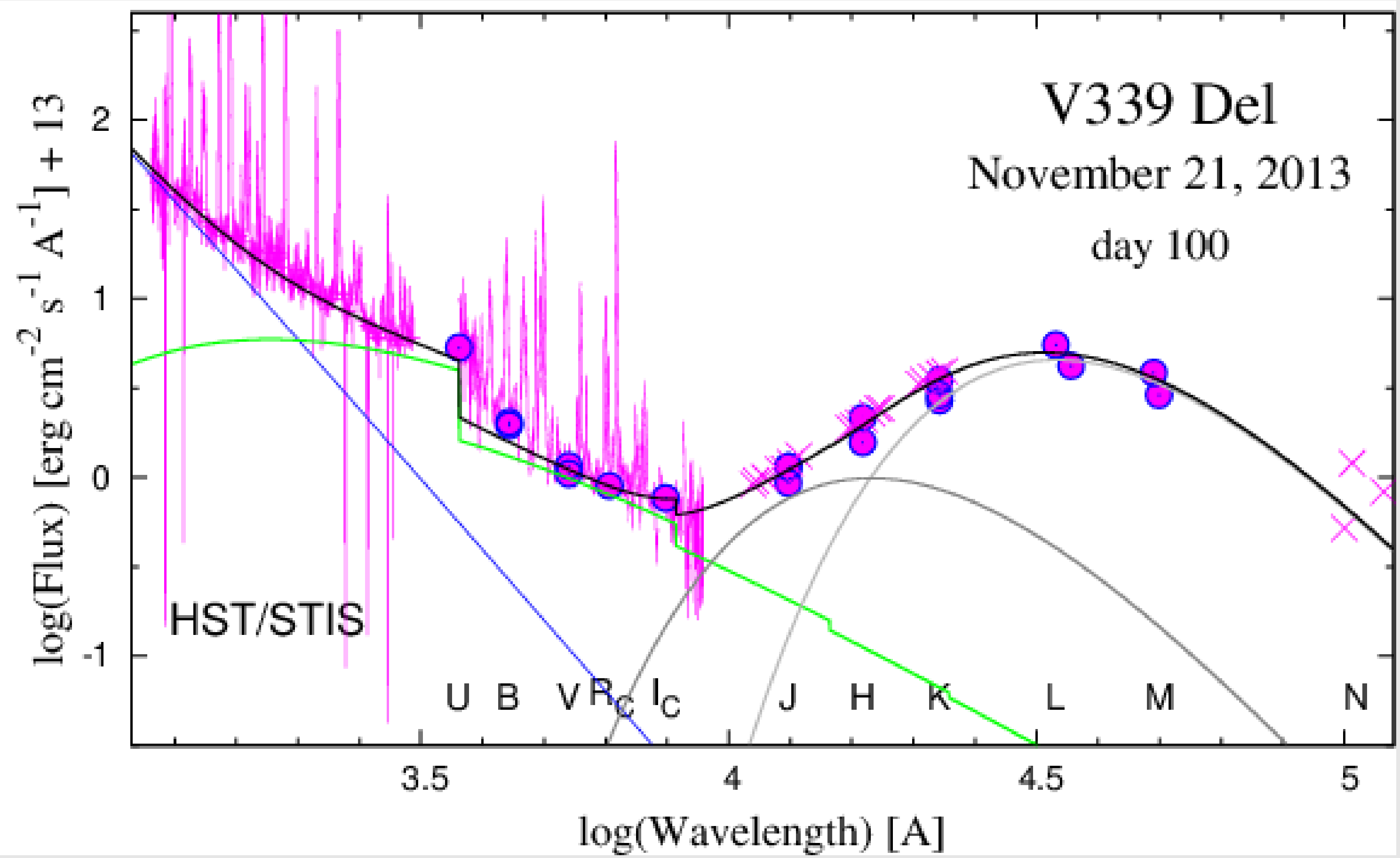
$$R_{WD}^{eff} = \theta_{WD} \times d, \quad L_{WD} = 4\pi d^2 \theta_{WD}^2 \sigma T_{BB}^4, \quad EM = 4\pi d^2 \times k_N$$

SSS-phase: day-100, November 21, 2013: UV – IR SED

Nebula: $T_e \sim 40{,}000$ K, $EM = 7.4 \times 10^{60}\,(d/4.5\mathrm{kpc})^2\ \mathrm{cm}^{-3}$.

Dust: $T_{D1} \sim 850$ K, $L_{D1} \sim 15{,}000\ L_{Sun}$

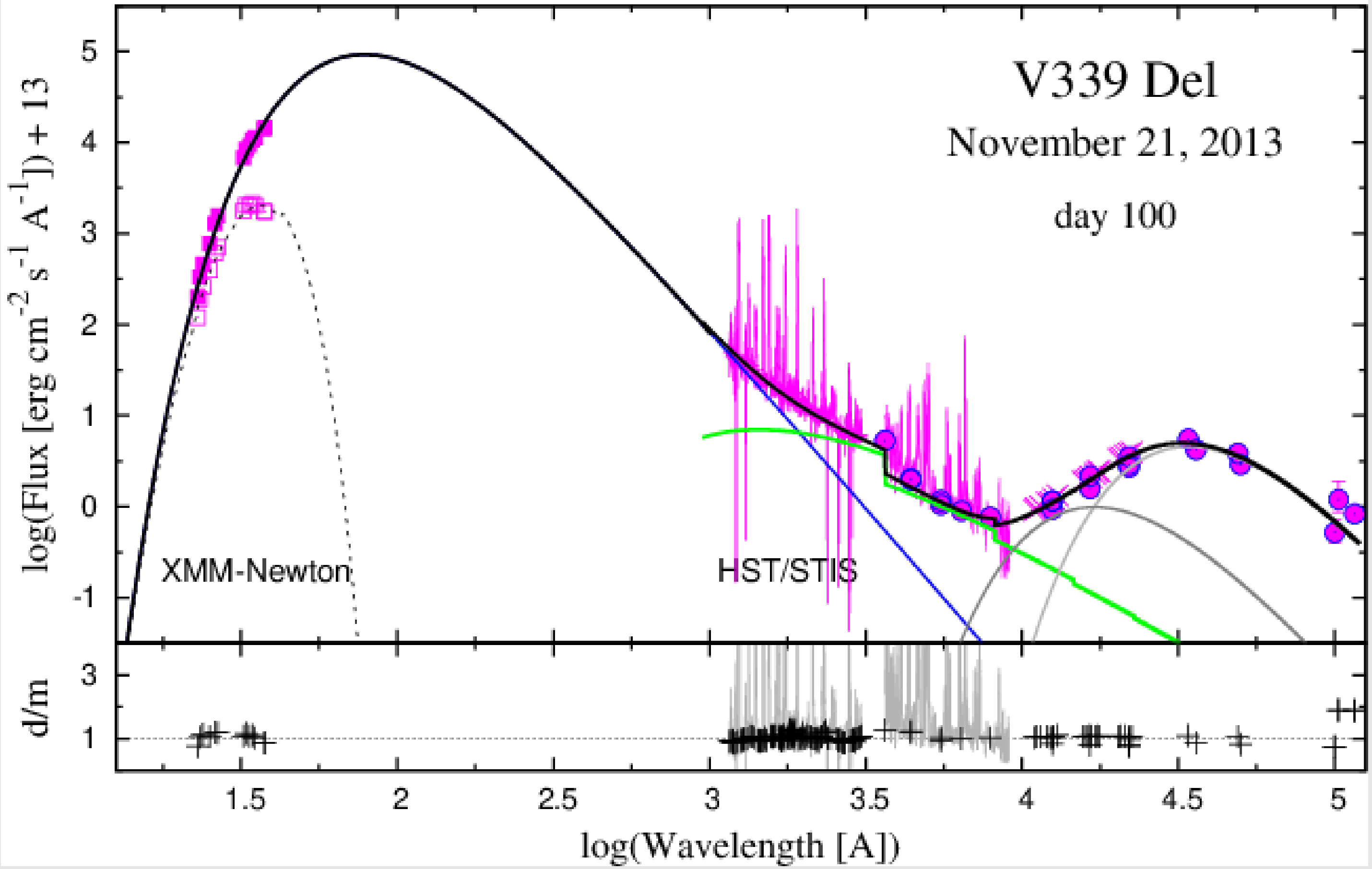
$T_{D2} \sim 1700$ K, $L_{D2} \sim 1{,}600\ L_{Sun}$



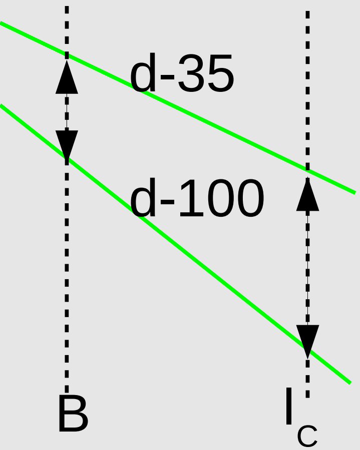
SSS-phase: day-100, November 21, 2013: X-ray – IR SED

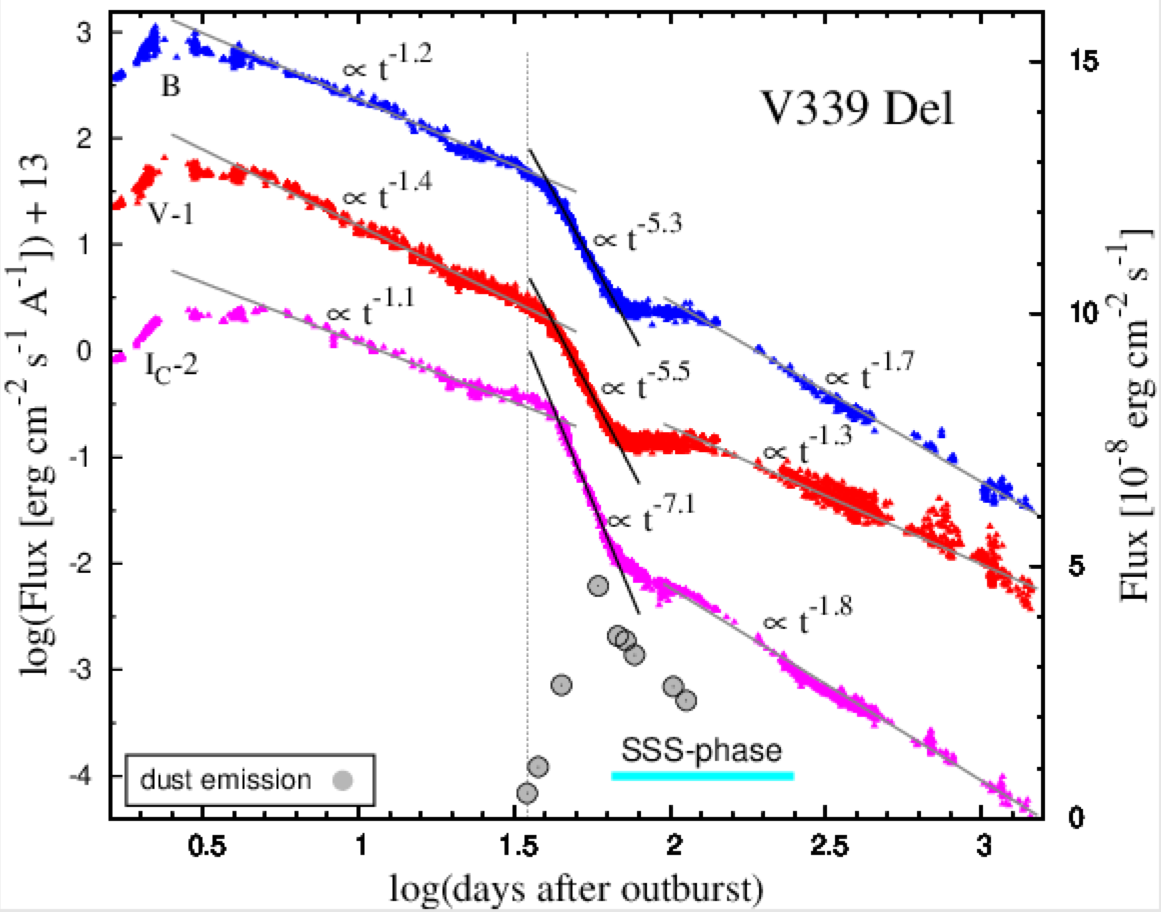
$L_{WD} \sim 700{,}000\ L_{Sun}$, $T_{BB} = 369{,}000$ K, $R_{WD} = 0.20\ R_{Sun}$

$N_H = 1.02 \times 10^{21}\ cm^{-2}$ <---> E(B-V) = 0.18 mag



Transition from day 35 to 100:
1. the steep 3-4 mag decline in the LC – a dust extinction ?



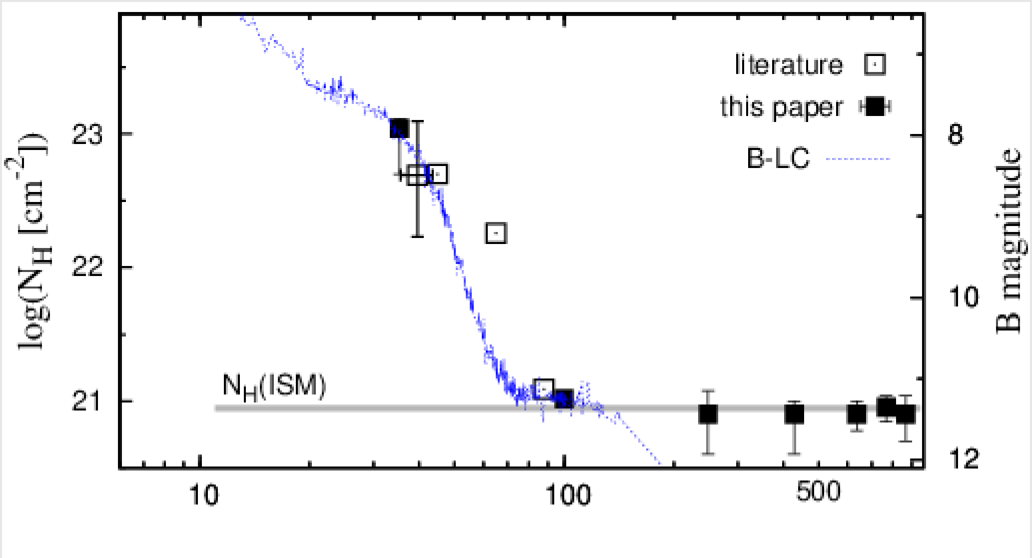


$\Delta B < \Delta I_C$, $F_\lambda \propto t^{-5} - t^{-7}$, but free expansion: $F_\lambda \propto t^{-3}$!

Explanation: $\uparrow T_{BB} \wedge \uparrow T_e \rightarrow$ shift to $\downarrow \lambda \Rightarrow \Delta I_C > \Delta B$.

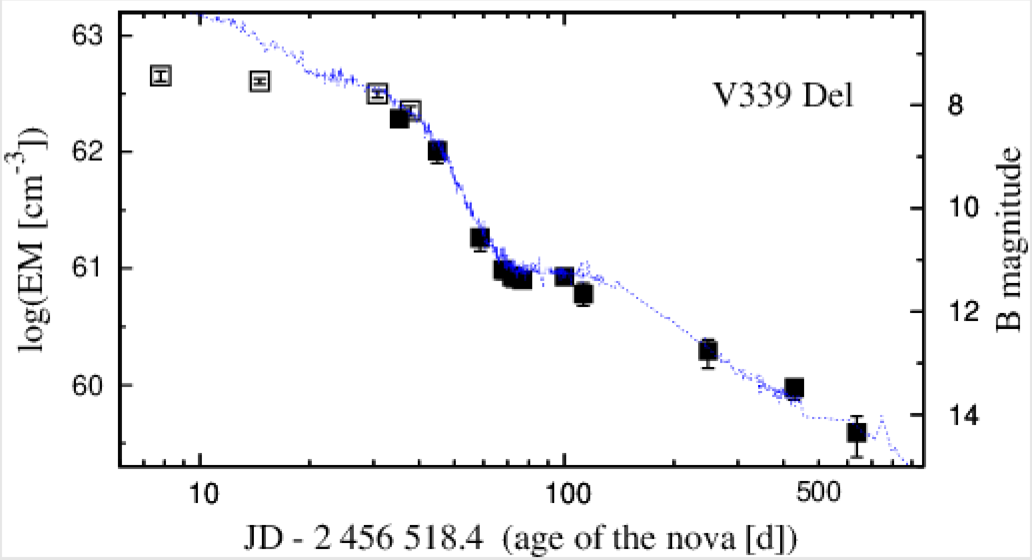
NO DUST EXTINCTION

Transition from day 35 to 100:
2. stopping-down the mass outflow from the WD



Column density of H atoms, N_H,
along the nova age.

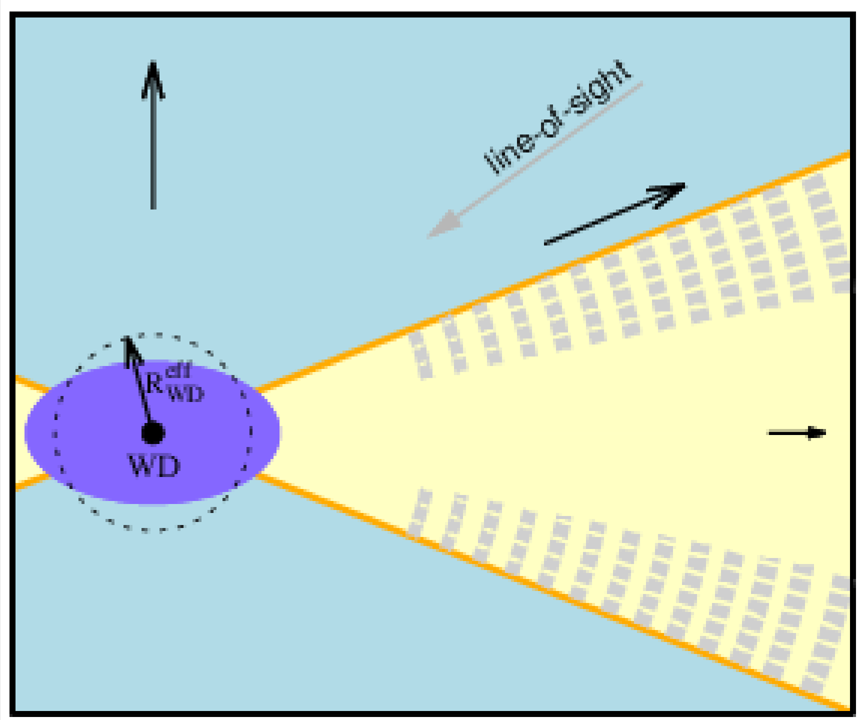
$$N_H(35) \sim 10^{23} cm^{-2} = N_H(ISM+CSM)$$
$$N_H(100) \sim 10^{21} cm^{-2} = N_H(ISM)$$

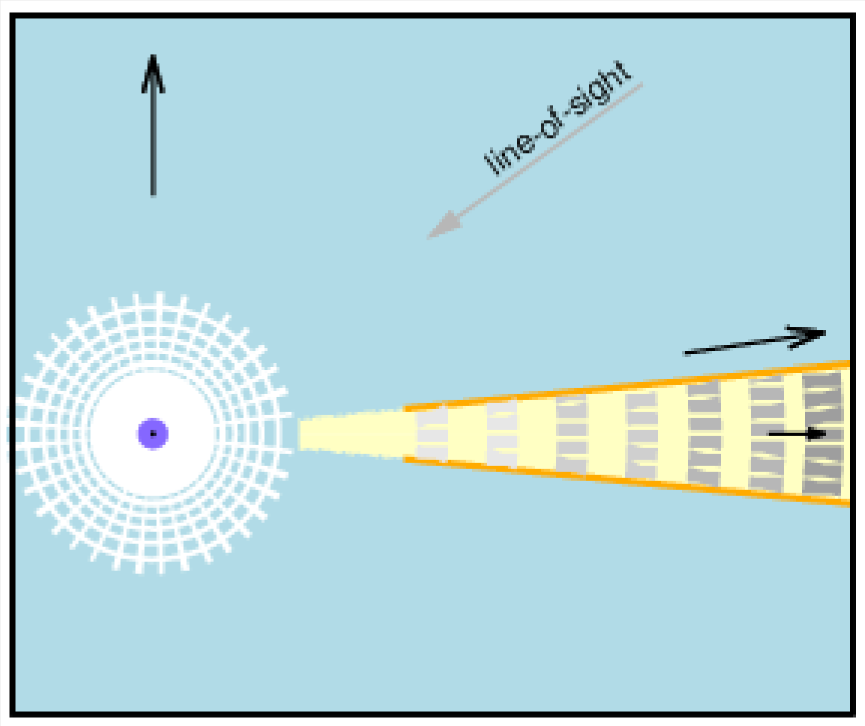


Emission measure along the nova age.

$$\dot{M}_{WD} \propto EM^{1/2}$$
$$\downarrow EM \rightarrow \downarrow \text{brightness}$$

Simultaneous fading of N_H, and EM
was caused by a drop in the dM/dt.
→ super-soft X-ray source phase





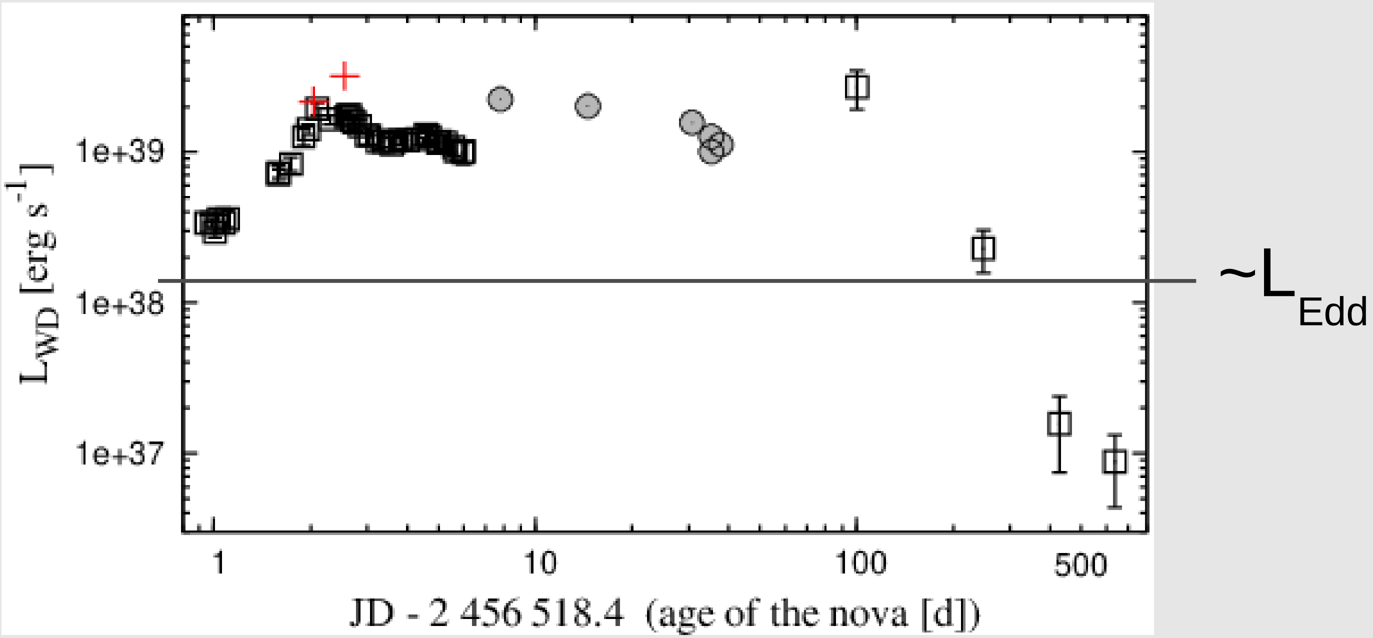
Sketch for nova ejecta from SED models inferred from SED models

Day 35:
Oblate shape of the WD: $L_H(\mathrm{WD}) \ll \alpha_B \times EM$

Yellow area: slow equatorially outflow
Blue area: high-velocity wind
Orange lines: shocks between both the ejecta, where dust can form (Derdzinski+17)
Gray elements: dust formation region

Day 100:
White: stopping-down the WD wind
N_H(CSM) → 0 : SSS phase
Elements: hotter & cooler dust

Long-lasting super-Eddington luminosity



Long-lasting super - L_{Edd} is not consistent with theoretical modeling

- Shaviv (1998): ↓opacity → ↑L_{Edd}
- Li et al. (2017): $\gamma - ray \wedge optical \; correlation$ → reprocessed emission from shocks
- Skopal et al. (2018): fueling the burning WD after the eruption by mechanism of radiation-induced warping + jets

Conclusions

Luminosity of the burning WD was super-Eddington
(from ~ day 2 to > day 100)

A biconical ionization structure with an equatorial dusty disk
(the hotter dust at the inner part)

Future work:
(i) to confirm the long-term super-Eddington luminosity for other novae
(ii) new theoretical modelling of the nova phenomenon is needed

Thank you for your attention

According to ApJ, 878:28 (2019 June 10)

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