Outburst of the classical slow nova V612 Sct

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in collaboration with

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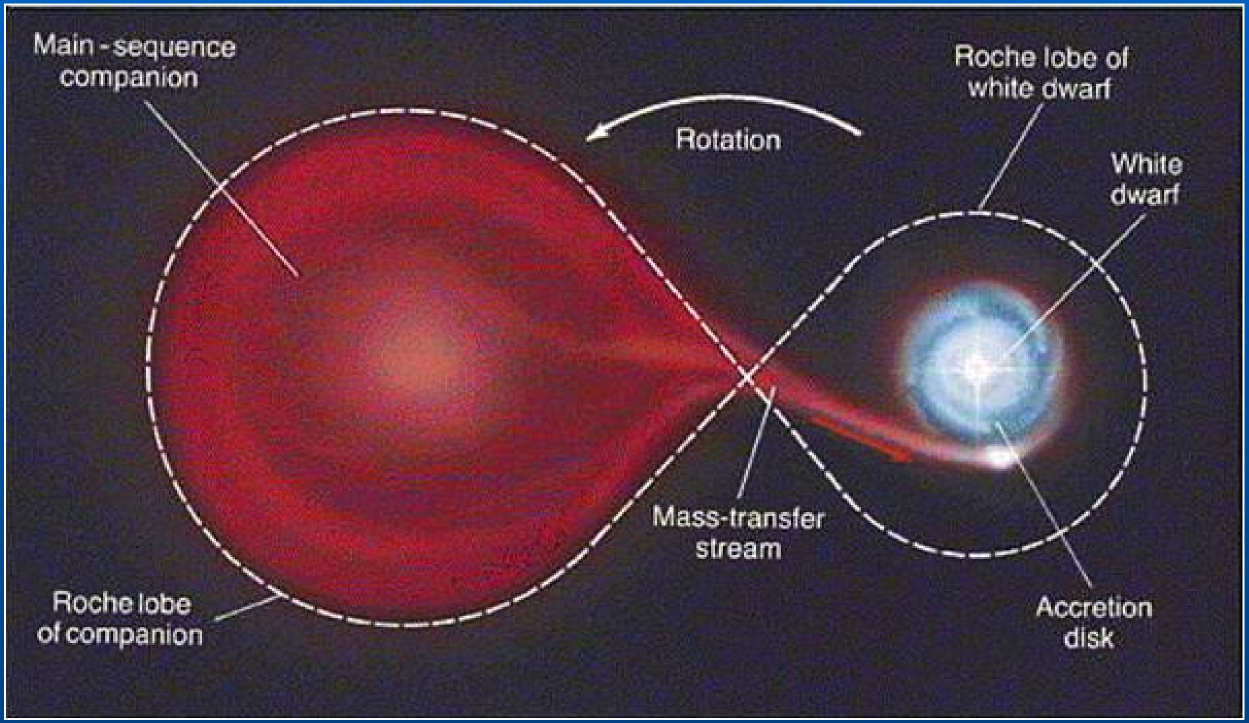


Classical novae are cataclysmic variables with 6 to 19 mag brightness increase, caused by thermonuclear runaway event on the surface of a white dwarf. They arise in close binaries with orbital periods of a few hours up to 2 days, consisting of a red
dwarf filling up its Roche-lobe and mass-accreting white dwarf. After the TNR, the photosphere of the white dwarf component of the nova expands to supergiant dimensions and engulfs the binary. Due to a strong wind a large part of the envelope is ejected and the photospheric radius shrinks.

Classification of novae based on a time interval in which nova fades by 2 or 3 magnitudes (*t2, t3)* from its maximum brightness.

The fast super-Eddington novae (*t2 < 13, t3 < 30 days)* have smooth light curves with well defined maxima. The slow Eddington novae (*t2 > 13, t3 > 30 days)* have structured light curves and many of them have standstills at maximum and dust formation at later stages (Downes & Duerbeck 2000, AJ 120, 2007).

Spectral classification

The spectra display either He/N or Fe II emission lines as the most prominent non-Balmer lines at maximum light. Fe II spectra are formed in a large circumbinary envelope of gas, whose origin is the secondary star, while He/N spectra are formed in white dwarf ejecta. In hybrid objects both classes of spectra appear sequentially due to changing parameters in the two emiting regions (Williams 2012, AJ 144, 98)

Nova V612 Sct 2017 (ASASSN-17hx)

•***Discovery:*** Stanek et al. (ATel 10523, 10524) with All Sky Automated Survey for SuperNovae, using data from the quadruple 14 cm "Brutus" telescope in Haleakala, Hawai on 2017 June 19.41 UT, ASASSN-17hx).

brightness V ~ 14.7 mag

position $\alpha(2000) = 18^{h}\ 31^{m}\ 45.918^{s}$

$\delta(2000) = -14°\ 18'\ 55.57''$

galactic l = 17.969° , b = - 2.232°

• ***Progenitor:*** Gaia Source ID 4104113504465549888, located 0.59" from the position, G = 19.102 mag (Kurtenkov et al. ATel 10527).

According to Saito et al. (ATel 10552), VVVX *Ks*-band observations taken during July and August 2016 show the presence of a faint source 0.84 arcsec from the reported target position with the Ks = 16.71±0.11 mag and coincide within 0.65 arcsec with the position of Gaia source.

The sources of photometric a spectroscopic data for investigation of the nova V612 Sct

CCD $UBVR_C\, I_C$ photometry:

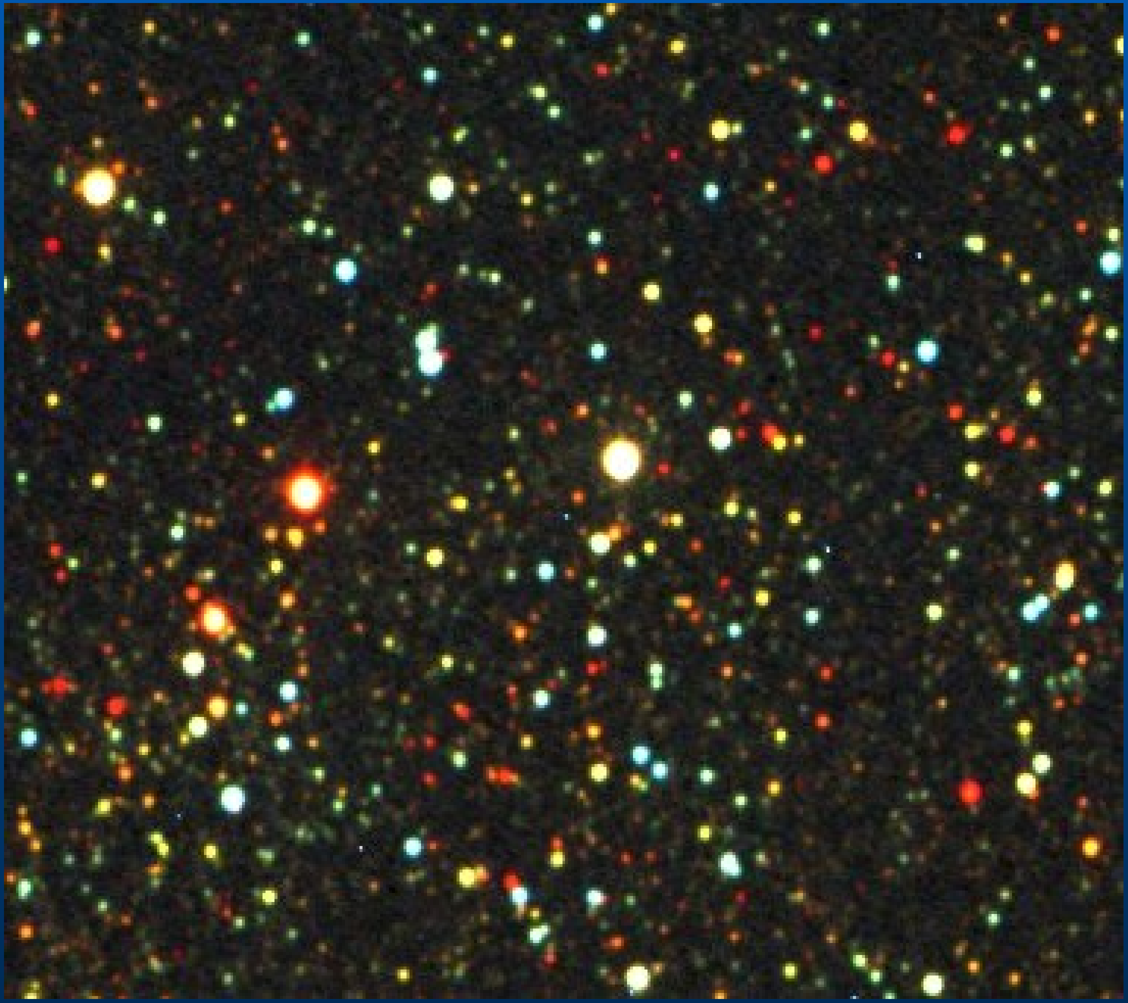
Two 0.6m Zeiss telescopes at AISAS Stará Lesná Observatory,
0.18m Maksutov at AISAS Stará Lesná Observatory,
0.5m Maksutov in Crimea Station of the Moscow State University,
AAVSO data

Spectroscopy:

1.30m telescope at AISAS Skalnaté Pleso Observatory, 4 spectra, R ~ 24 000
0,6m Zeiss telescope at AISAS Stará Lesná Observatory, 20 spectra R ~ 12 000
Astronomical Ring for Access to Spectroscopy (ARAS) group spectroscopy:
140 spectra, R ~ 5 000 - 13 000 (71 spectra taken by J. Guarro)
http://www.astrosurf.com/aras/Aras_DataBase/Novae/2017_NovaSct2017.htm

ATELs

Combined BVI_C CCD image of the nova (V = 8.6 mag) with 18 cm Maksutov at the AISAS Stará Lesná Observatory on August 1, 2017.



Nova V612 Sct in ATels.

- June 24, 2017, low resolution spectra (R ~ 500), 2m telescope of Rozhen observatory: Hα, Hβ, He I, He II, NII and NIII emission lines (He/N type), RVs of absorptions in He I P Cyg profiles give expansion velocity 990 km/s, Kurtenkov et al. (ATel 10527).

- June 26.1, 29.02 medium resolution spectroscopy (R ~ 5400), 2m Liverpool telescope, Balmer and He I P Cyg profiles. FWHM of Hα emission 800 km/s. Hβ absorptions components at –860 and –520 km/s. Mg II and Si II emissions, (Williams & Darnley, ATel 10542).

- June 29.8 – July 4.8 ARAS low resolution spectroscopy (R ~ 580 – 2650), He I emissions weakened and Fe II emissions appeared, P Cyg absorptions extending to – 800 km/s (Berardi et al., ATel 10558).

- July 10, brightness premaximum, high and low resolution spectroscopy, 1.82 and 1.22 m telescopes in Asiago and 1.5m telescope in Tubitak (Munari et al. ATel 10572). Spectra show prominent emissions of Balmer and Paschen series, FeII lines, SiII, OI and CaII lines. Textbook example of the Fe II nova. P-Cyg absorptions of Fe II multiplet 42 at –451, –359 and –285 km/s. Reddening E(B-V) = 0.68, derived fom EW of diffuse interstellar band at 6614 Å.

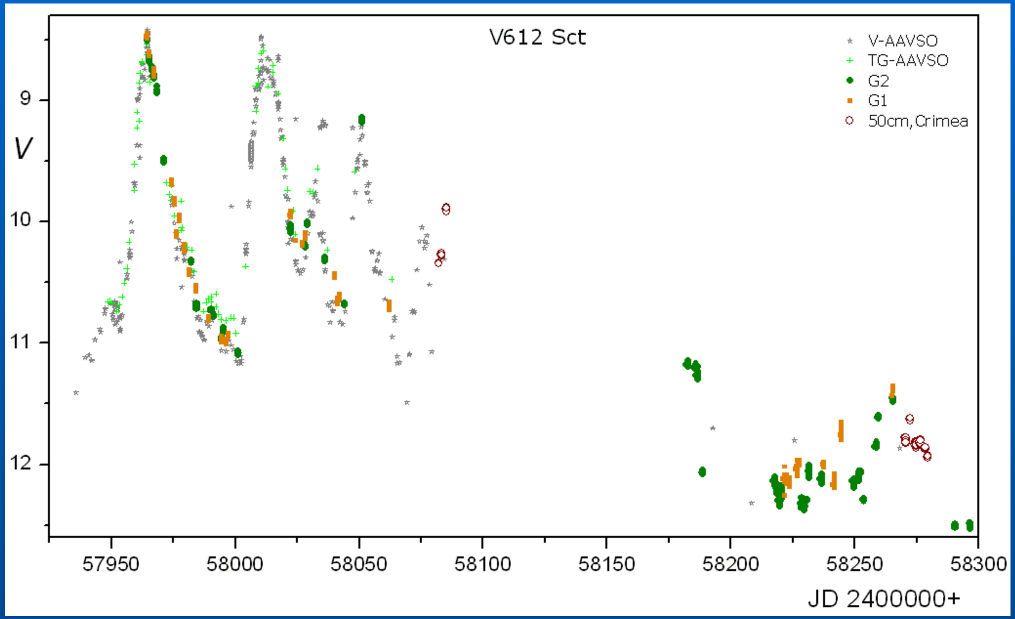
- July 26.61 and 27.58 (3 and 2 days before the brightness maximum), spectroscopy by 2.3m Vainu Bappu telescope, Kavalur, India. The P Cyg absorptions developed in Balmer and Fe II

- Swift observations with 30 cm UVOT telescope: June 30. Reddening E$(B-V)$ = 0.8±0.1 derived from significant 2175 Å dip. NII] and NIII] emissions with FWZI 4600 km/s. In August 9, large Fe II curtain present in 1800 – 3800 Å part of the spectrum.

- The peak brightness reached on July 30.1 UT at B=9.65, V = 8.44. In August 12.8, optical spectra (Munari et al. ATel 10641) dominated by Fe II, with He I growing in intensity, sharp absorption in Balmer lines at velocity –250 km/s, superimposed on the emission component that extent at its base from about –1000 to +1000 km/s. The interstellar absorption lines from NaI D1,D2 doublet composed by several components. The total equivalent width indicates a reddening E$(B-V)$ = 0.62 following the calibration by Munari and Zwitter (1997, A&A 318, 269).

- September 11, echelle spectrum during re-brightening with Varese 61 cm telescope (Munari et al. ATel 10736). In Balmer and Fe II emission lines multi-component P-Cyg absorptions. The absorptions for Hα is composed by 3 components at –500, – 875 and –1130 km/s. FWHM of Hα emission 770 km/s.

- ARAS spectra from June 29 till Sept. 9 with resolution from 580 to14000, depending on the spectrograph (Alpy 600, LISA, LHIRES, eShel) covering 3800-7200 A and S/N 50-100. All lines varied in strength and profile with light curve changes (Guarro et al. ATel 10737).



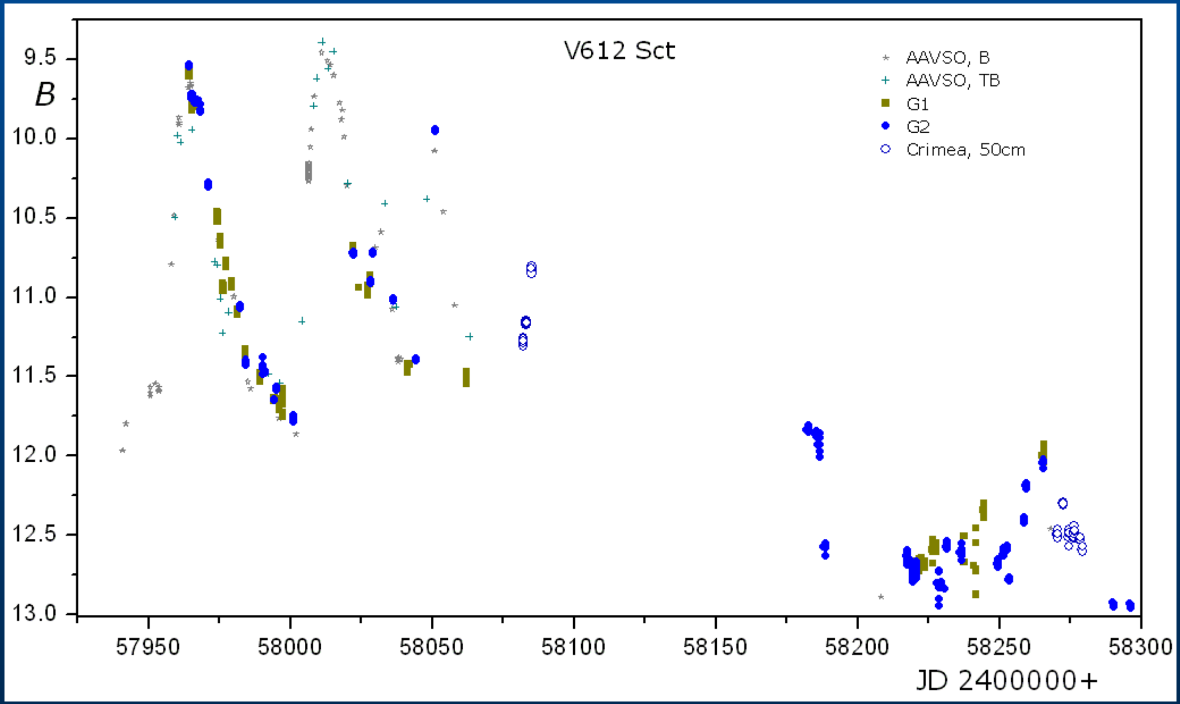
CCD photometry of V612 Sct , our observations and AAVSO data.

The brightness maximum of the nova:
2017July 29.9886 UT (JD 2457964.4886)

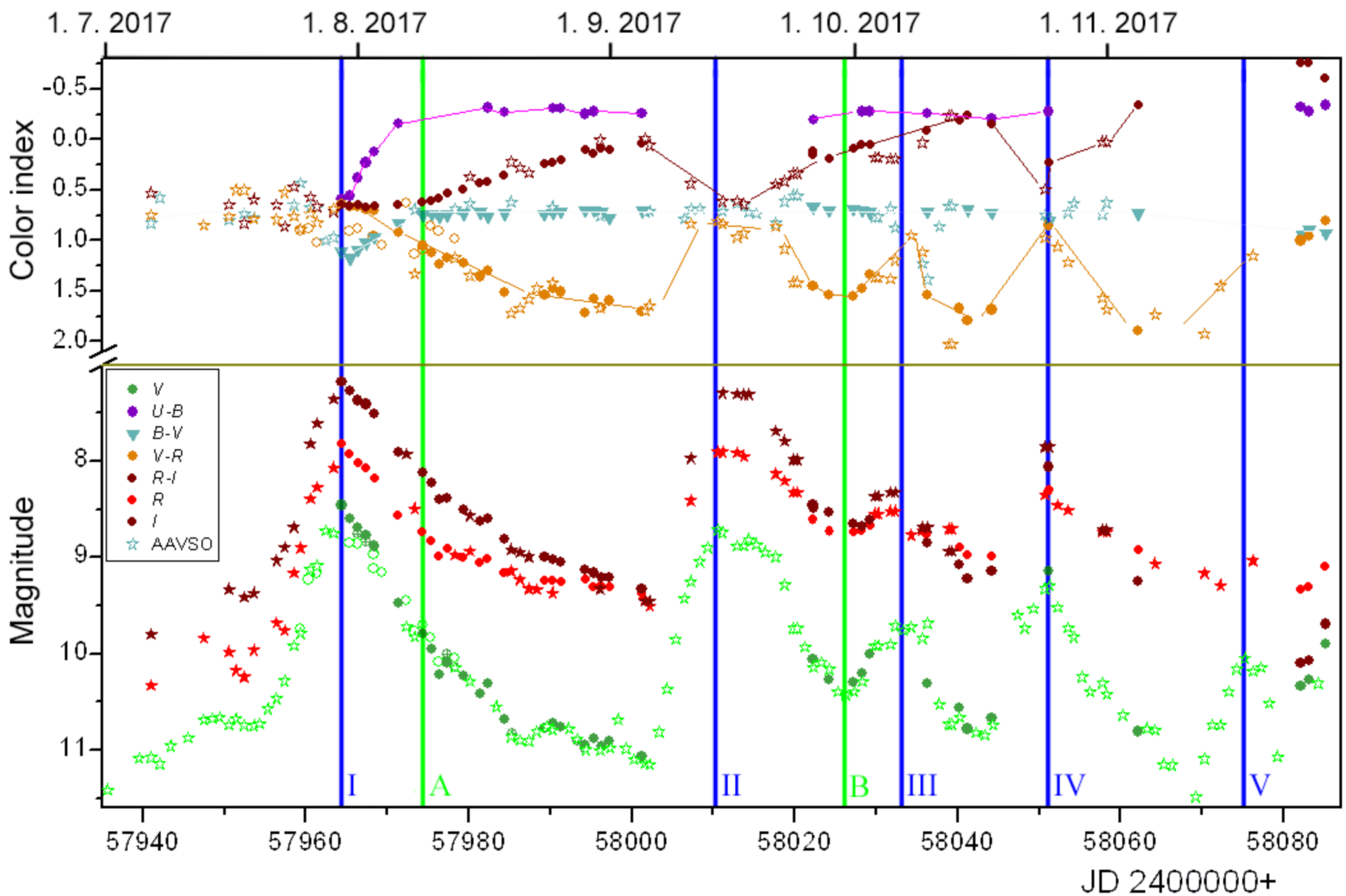
$$V_{max} = 8.42 \text{ mag}$$

$$B_{max} = 9.53 \text{ mag}$$

$t_{3,V} = 105$ days, $t_{3,B} = 224$ days,



Photometry of the nova V612 Sct

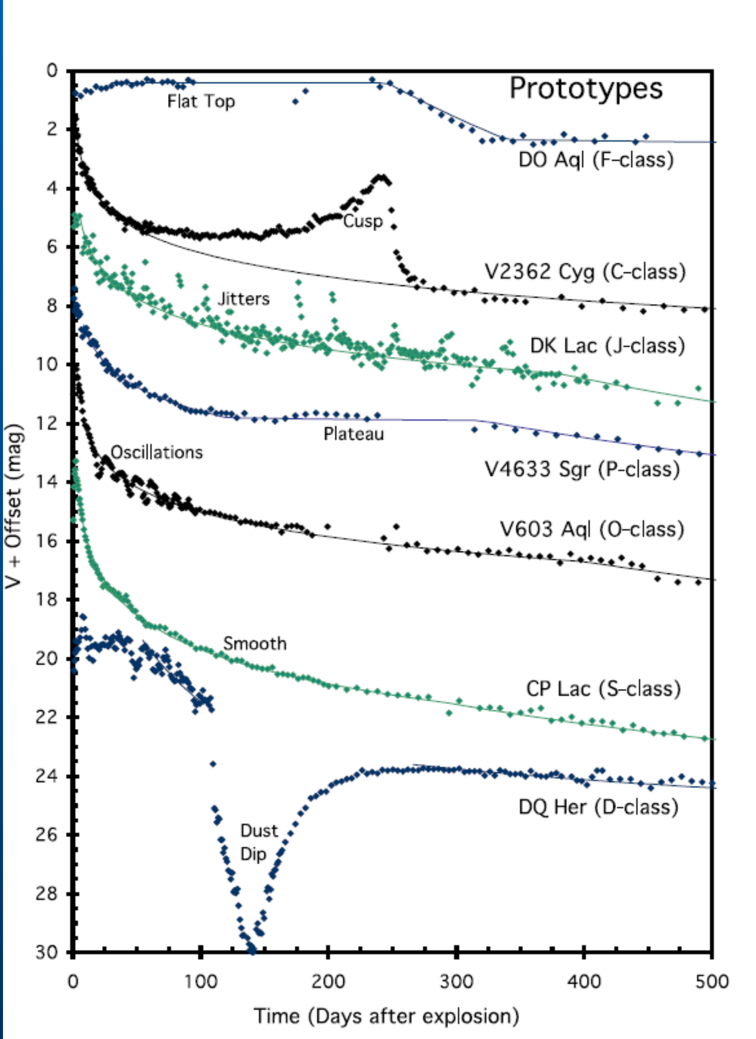


Classification of novae according to the properties of their light curves.

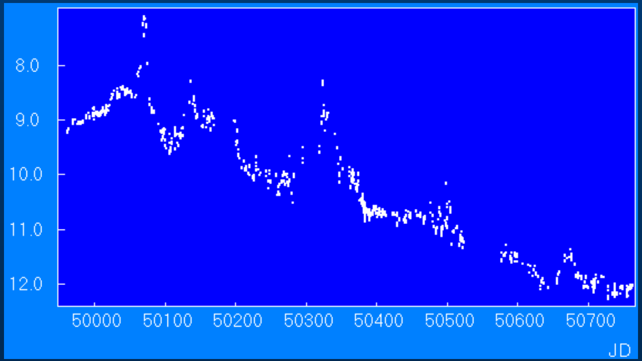
CATALOG OF 93 NOVA LIGHT CURVES: CLASSIFICATION AND PROPERTIES
Strope et al. 2010, AJ, 140, 34

Definitions and Examples of Light Curve Classes

Class	Definition	Examples
S	Smooth; power-law decline with no major fluctuations	CP Lac, V1668 Cyg, V2275 Cyg
P	Plateau; smooth decline interrupted by a long-lasting nearly flat interval followed by steeper decline	V4633 Sgr, CP Pup, RS Oph
D	Dust dip; decline interrupted by fast decline, minimum, and recovery to just below original decline	DQ Her, FH Ser, V705 Cas
C	Cusp; power-law decline plus secondary maximum with steepening rise then steep decline	V2362 Cyg, V1493 Aql, V2491 Cyg
O	Oscillations; smooth decline with interval showing quasi-sinusoidal variations	V603 Aql GK Per, V1494 Aql
F	Flat topped; smooth light curve with an extended interval at the peak with near constant brightness	DO Aql, V849 Oph, BT Mon
J	Jitter; decline displays substantial variability often as short-duration brightenings	DK Lac HR Del, V723 Cas



The light curve of the nova V612 Sct allow to classify it as a slow nova of the J-class with multiple peaks on the decline. Similar objects: V723 Cas, HR Del, V5558 Sgr, V4745 Sgr



The light curve of V723 Cas (Chochol & Pribulla, 1997, CAOSP 27, 53)

(JD 24000+)

Basic parameters of the nova V612 Sct

V and *B* light curves were used to find the rates of decline:

$t_{3,V} = 105$ d, $t_{3,B} = 224$ d,

We estimated the absolute magnitudes of this slow nova at maximum using the MMRD relations

1) $MV_{max} - t_3$ relation of Schmidt (1957, ZfA 41, 182)

$MV_{max} = -11.75 + 2.5 \log t_3$ $MV_{max} = -6.70$

2) $MV_{max} - t_3$ relation of de Vaucouleurs (1978, ApJ 223, 351)

$MV_{max} = -11.3 + 2.4 \log t_3$ $MV_{max} = -6.45$

3) $MV_{max} - t_3$ relation of Downes & Duerbeck (2000, AJ 120, 2007)

$MV_{max} = (-11.99 \pm 0.56) + (2.54 \pm 0.35) \log t_3$ $MV_{max} = -6.86$

$$MV_{max} = -6.67 \pm 0.09$$

Basic parameters of the nova V612 Sct

1) $MB_{max} - t_3$ relation of Pfau (1976, A&A 50, 113)

$$MB_{max} = -10.67 + 1.80 \log t_3 \qquad MB_{max} = -6.44$$

2) According to van den Bergh & Younger (1987, A&AS 70, 125), the mean intrinsic value of $B - V$ colour index for novae in maximum is

$$MB_{max} - MV_{max} = 0.23 \pm 0.06, \text{ so} \qquad MB_{max} = -6.44$$

$$MB_{max} = -6.44 \pm 0.15$$

Using the formula given by Livio (1992, ApJ 393, 516)

$$MB_{max} = - 8.3 - 10.0 \log (M_{wd} / M_{sun}),$$

we estimated the mass of the white dwarf in V612 Scuti 2017 as

$$M_{wd} = 0.65 \pm 0.02\ M_{sun}$$

Basic parameters of the nova V 612 Sct

Colour excess was found:

• from the comparison of the observed *B-V* index at maximum $(B\text{-}V)_{max}$ = 1.11, affected by extinction, with the intrinsic colour index $MB_{max} - MV_{max} = 0.23$

$$E(B\text{-}V) = 0.88$$

• from the relation of van den Bergh & Younger (1987, A&AS 70, 125) who found that novae 2 mag below maximum have an unreddened colour index

$$B\text{-}V = -0.02 \pm 0.04$$

Observed colour index is $(B\text{-}V)_{obs} = 0.68$, so

$$E(B\text{-}V) = 0.70 \pm 0.04$$

• from the 2175 Å dip caused by an interstellar extinction in UV Swift spectra (Kuin et al. 2017, ATel 10636)

$$E(B\text{-}V) = 0.8 \pm 0.1$$

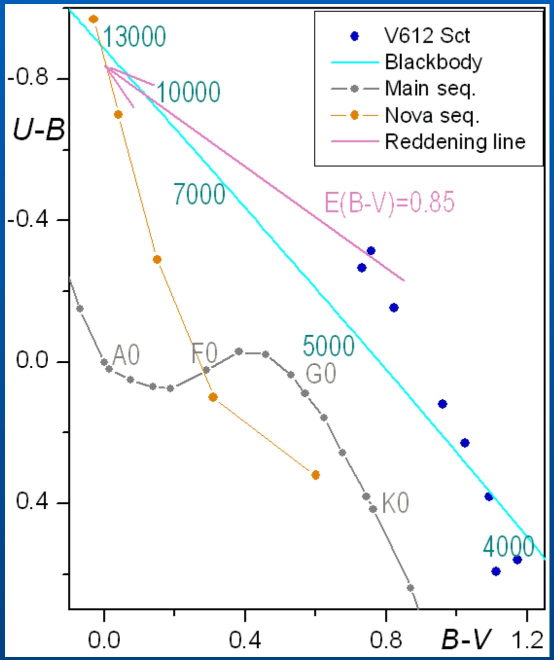
• from the equivalent width of the diffuse interstellar band at 6614 Å (Munari et al. 2017, ATel 10572)

$$E(B\text{-}V) = 0.68$$

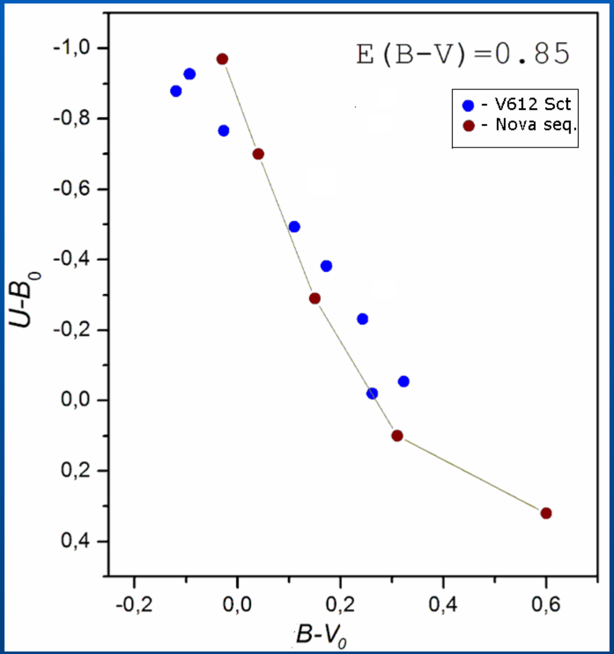
• from the interstellar NaI D1,D2 doublet (Munari et al. 2017ATel 10641)

$$E(B\text{-}V) = 0.62$$

• from the comparison of the position of the nova Sct 2017 affected by extinction with the position in classical novae sequence in *(U-B,B-V)* diagram (Hachisu & Kato, 2014, ApJ 785, 97).



E(*B-V*) = 0.85



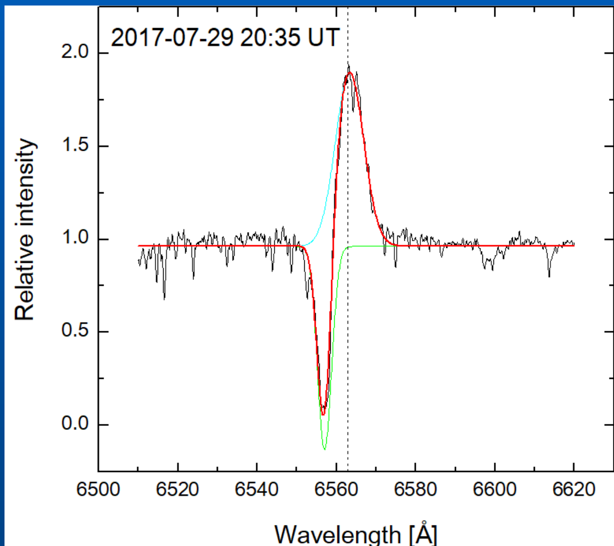
Mean value: $E(B\text{-}V) = 0.755 \pm 0.039$

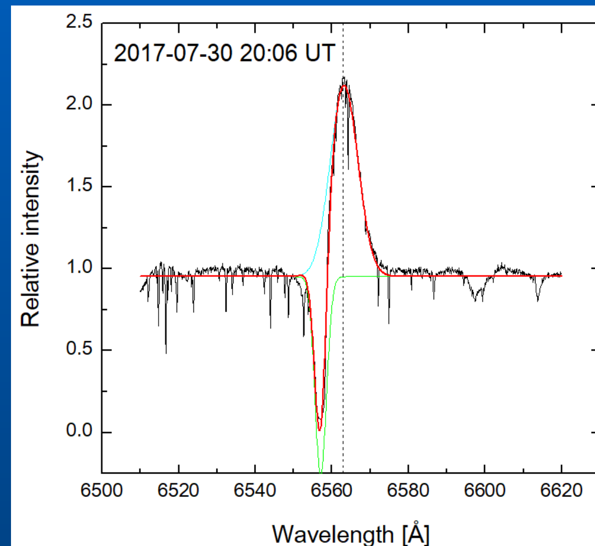
Corresponding absorption: $A_V = 2.34 \pm 0.12$

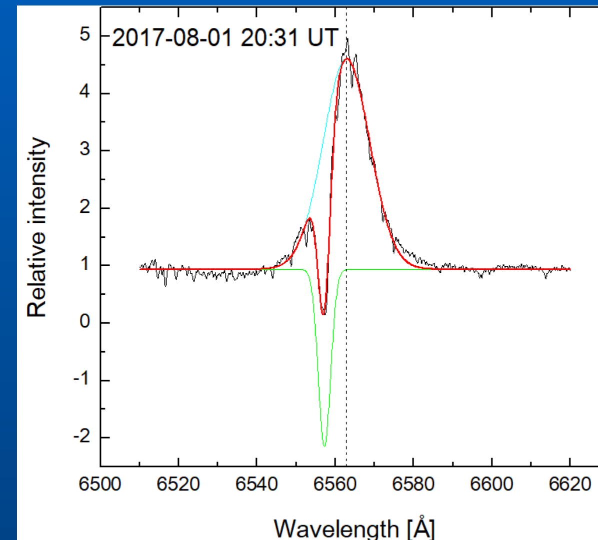
Distance modulus: $V_{max} - M_{V,max} = 15.08 \pm 0.08$

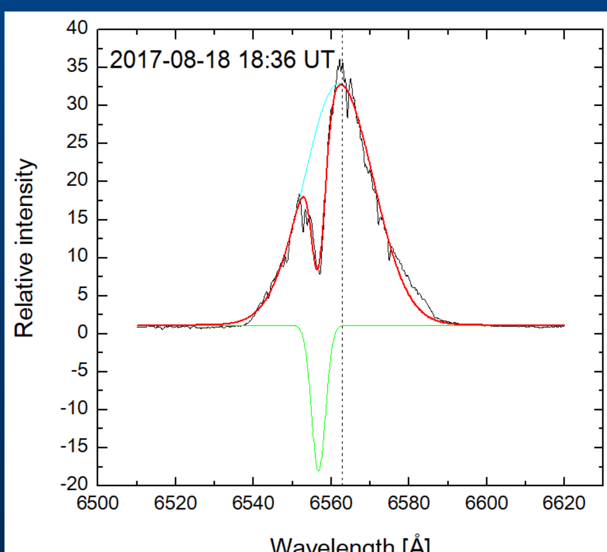
Distance to the nova: $\boldsymbol{d = 3.5 \pm 0.3}$ **kpc**

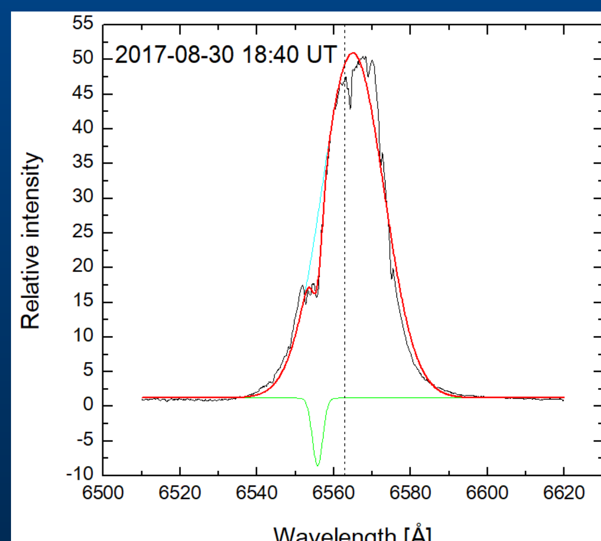
Spectroscopy of the nova V612 Sct.





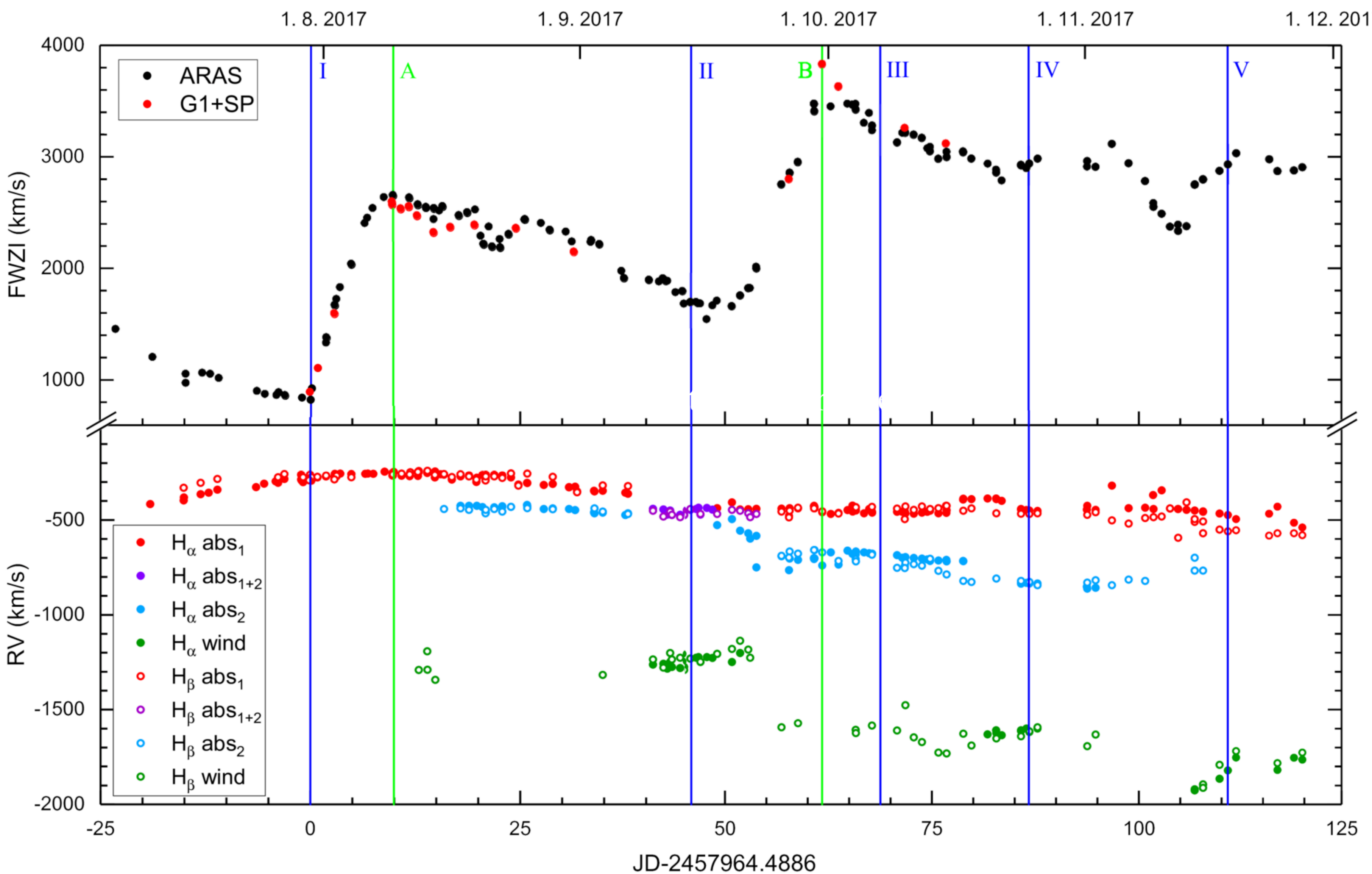






We selected the regions of spectrum around the Hα and Hβ line and fitted continuum by the second order polynomial. We added a few Gaussian peaks based on the shape of the line, emission and absorption features. The initial emission peak was selected to cover the shape of the wings and the intensity at the central wavelength. Then the FWZI was found and expressed in velocity scale.

FWZI of the Hα main emission components and RVs of Hα and Hβ P Cyg absorptions

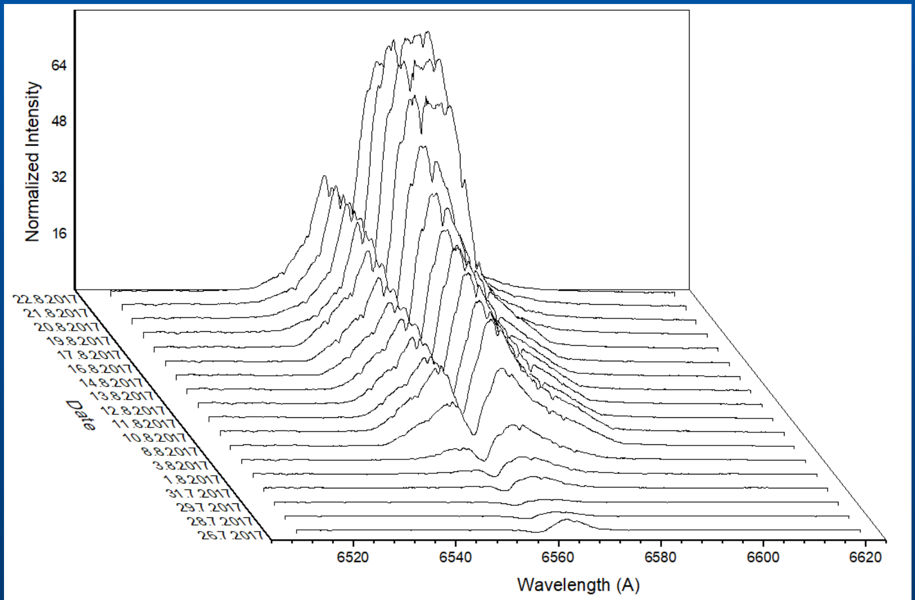


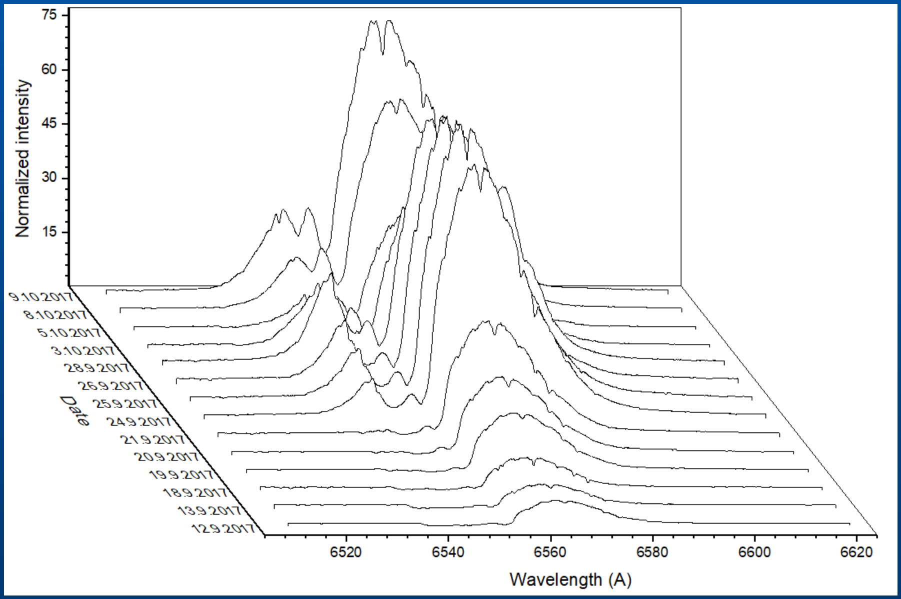
Hα spectroscopy of the nova V612 Sct.

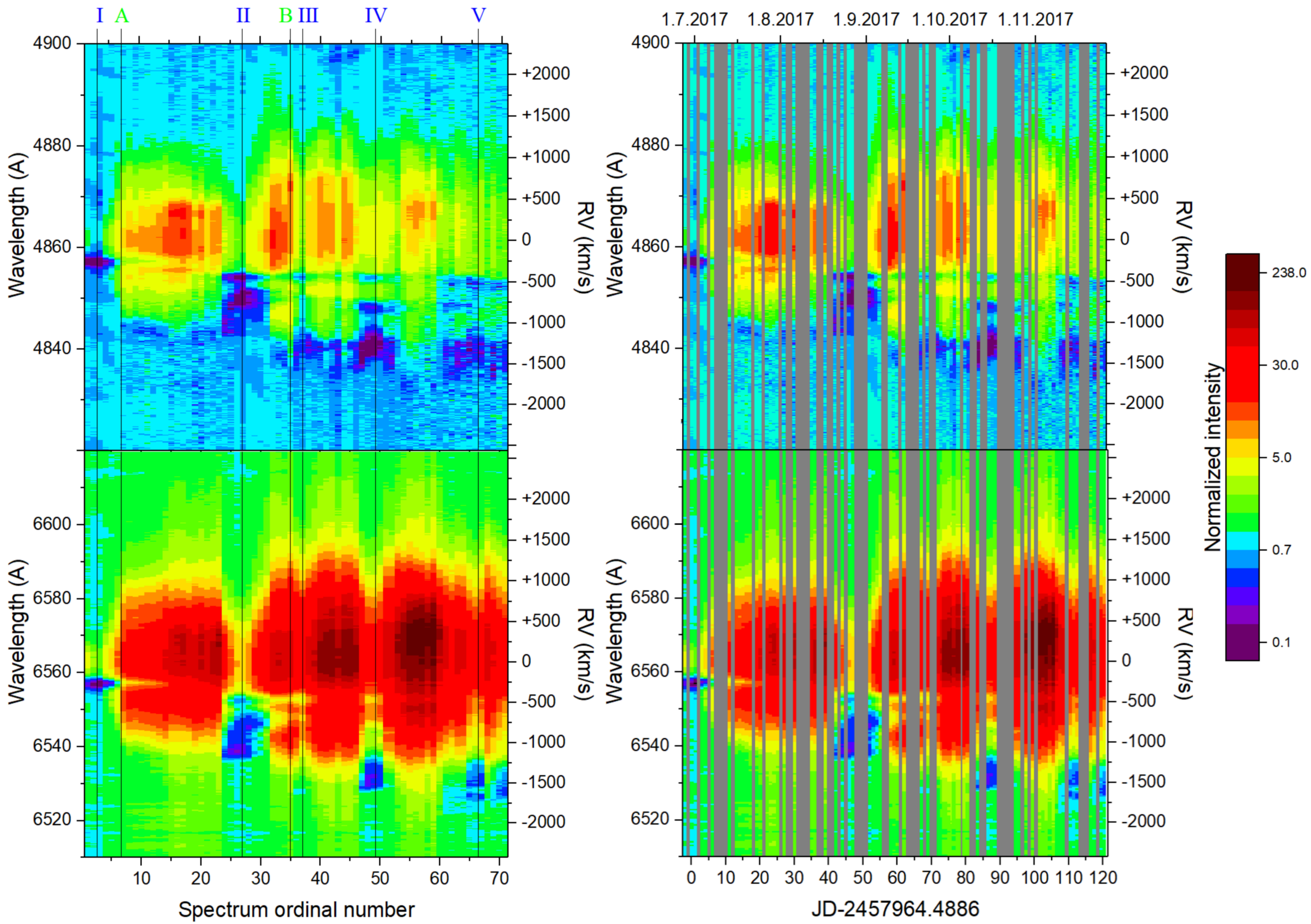
Evolution of the Hα profile

During the brightness maximum I

During rebrightenings II and III





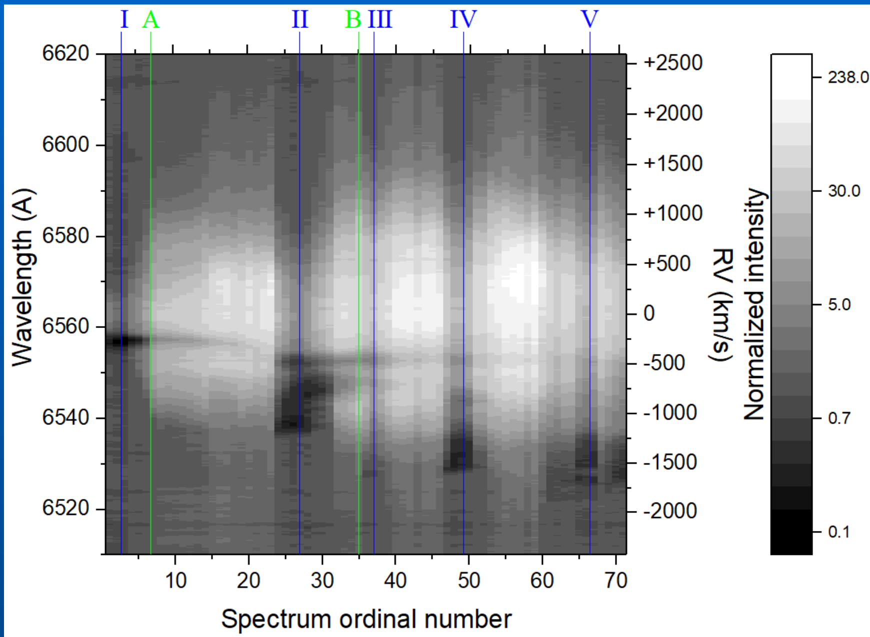


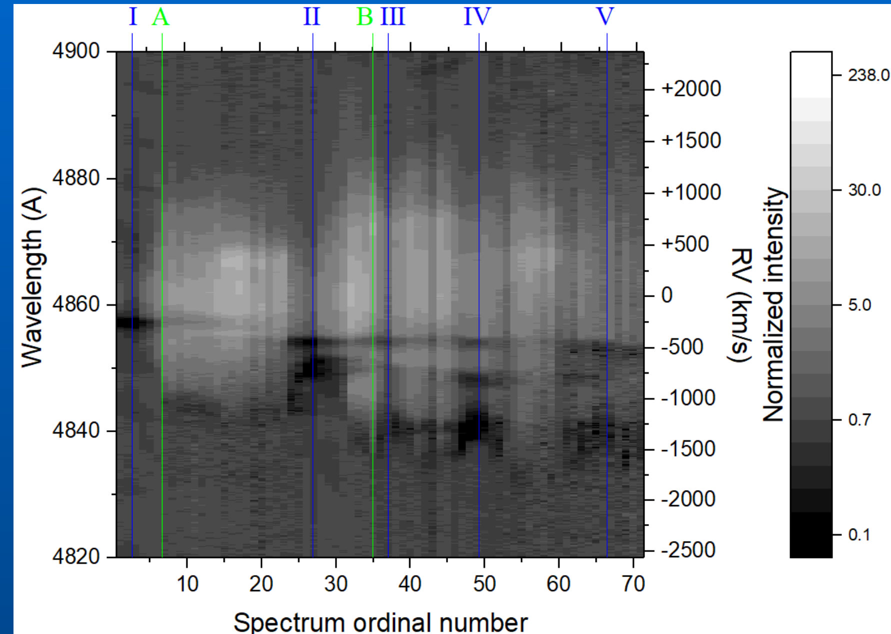
I
A
II
B
III
IV
V
1.7.2017
1.8.2017
1.9.2017
1.10.2017
1.11.2017
Wavelength (A)
RV (km/s)
Spectrum ordinal number
JD-2457964.4886
Normalized intensity
238.0
30.0
5.0
0.7
0.1

Hα and Hβ spectroscopy of the nova V612 Sct

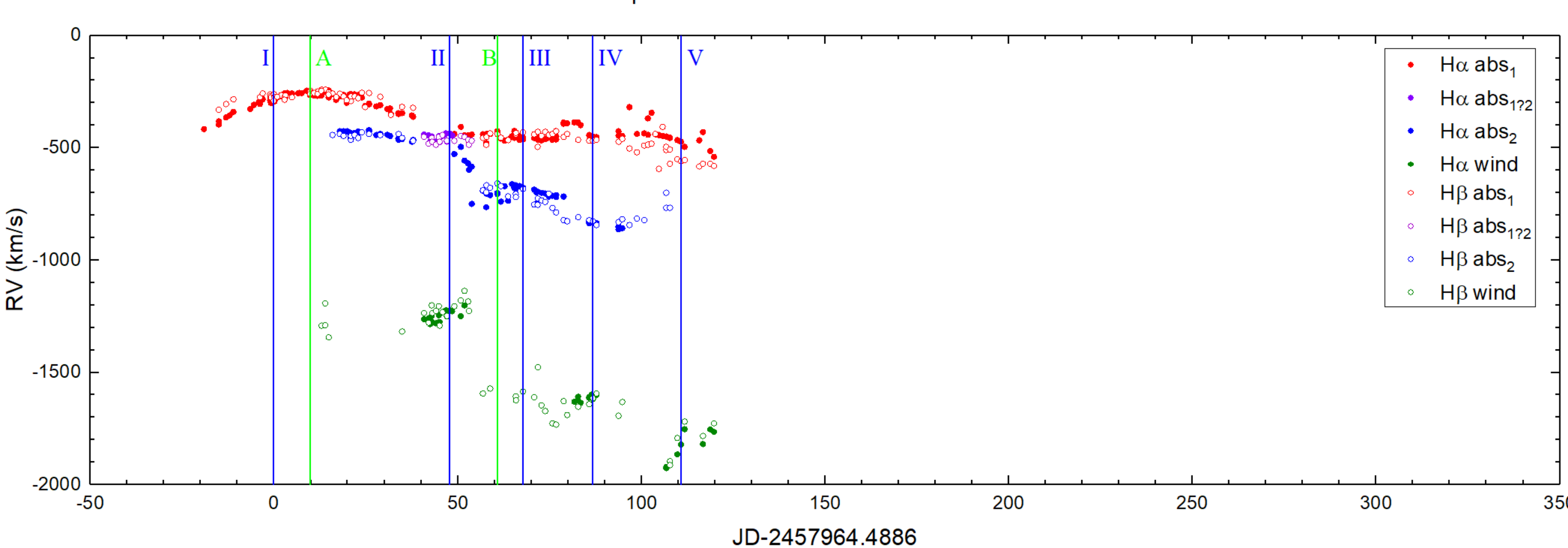
Appearance of the strong P Cyg absorptions in Balmer lines during the brightness maximum of the nova and rebrightenings maxima of the nova V612 Sct can be explained by re-expansion of the nova photosphere as suggested by Tanaka et al. (2011 PASJ 63, 911) for V5558 Sgr and similar novae.

Csák et al. (2005, A&A 429, 529) interpreted the fact, that majority of spectral lines switched back to strong P Cyg profiles during mini-outbursts similar to the spectra during a main outburst of the nova V4745 Sgr, by repetitive instabilities of the hydrogen shell burning on the surface of the white dwarf. Episodic fuel burning during rebrightenings was discussed by Pejcha (2009, ApJ 701, L119).





Absorption-features evolution of Nova Scuti 2017



Expanding shell of the nova V612 Sct

The expanding shell of the nova V612 Sct consists of two major components: an inner slow main high-mass envelope in the form of equatorial ring and an outer fast tenuous low-mass envelope shaped and accelerated by spherical and polar winds. The similar structure of the expanding shell was proposed by Chochol et al. (1997, Astron. Astrophys. 318, 908) for the Nova V1974 Cyg.

The long term behavior of absorptions could indicate long-term change of the inclination of the polar outflow suggesting the precession of the accretion disk with the period of about 170 days.

The exact kinematical model of the expanding shell requires the high-resolution spectroscopy in nebular stage of the nova and direct radio and optical images of the expanding shell.

Kato and Hachisu (2011, ApJ 743,157) proposed two types of nova evolution that can occur in low-mass white dwarfs of ~ $0.5 – 0.7\ M_{sun}$.

The flat peak in symbiotic nova PU Vul suggest for evolution with no indication of strong winds.

They proposed a transition from static evolution with no optically thick wind to usual evolution with the optically thick winds for slow novae V723 Cas, V5558 Sgr and HR Del that show long lasting multipeak. The presence of a companion deep inside the envelope triggers this transition, accompanied by oscillatory behaviour caused by relaxation process. The solid line indicate the composite light curve model of $0.6\ M_{sun}$ WD with solar composition.

The nova V612 Sct with $0.65\ M_{sun}$ WD belongs to the same group of slow novae.

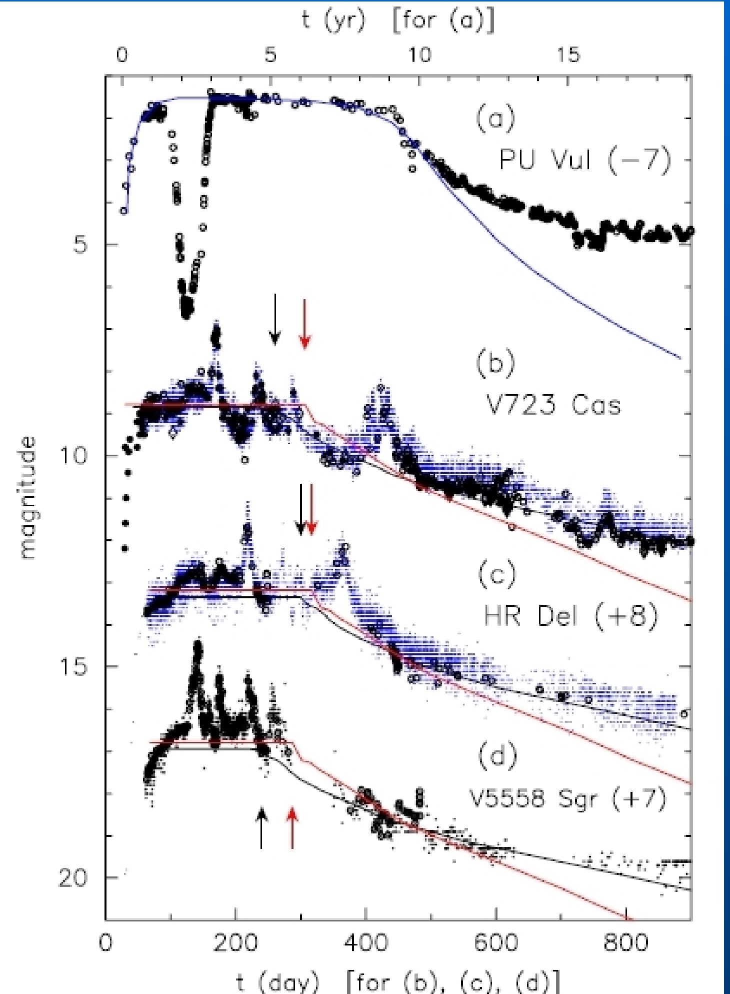


Figure 6. Comparison of light curves among PU Vul, V723 Cas, HR Del, and V5558 Sgr. PU Vul is shifted upward by 7 mag and HR Del and V5558 Cyg downward by 8 and 7 mag, respectively. The upper timescale is for PU Vul and the lower one is for the other three novae. (a) PU Vul: data taken from Kato et al. (2011). The dips at $t = 2.2$ yr and 15.7 yr are eclipses. (b) V723 Cas: diamonds (Chochol & Pribulla 1997), filled small circles (IAUC Nos. 6213, 6214, 6227, 6233, 6256, 6283, 6331, 6358, 6428), open circles (AAVSO, V-mag), dots (AAVSO, visual). (c) HR Del: open circles (Stokes 1967; Pohl 1967; Nha 1967; Onderlička & Vetešník 1968; O'Connell 1968; Grygar 1969; Mollerus 1969; Mannery 1970; Barnes & Evans 1970, V), dots (AAVSO, visual). (d) V5558 Sgr: open circles (AAVSO, V), dots (AAVSO, visual). The solid lines indicate the composite light curve model of $0.55\ M_\odot$ WD with $X = 0.55$, $C + O = 0.2$, $Z = 0.02$ (red line), and $0.6\ M_\odot$ WD with the solar composition (black line). The arrows indicate the switching point from a static to a wind evolution: $\log T$ (K) = 3.88 (red) and 3.93 (black).

Thanks for your attention!