The Nature of the Progenitor and the Remnant of Helium Nova V445 Puppis

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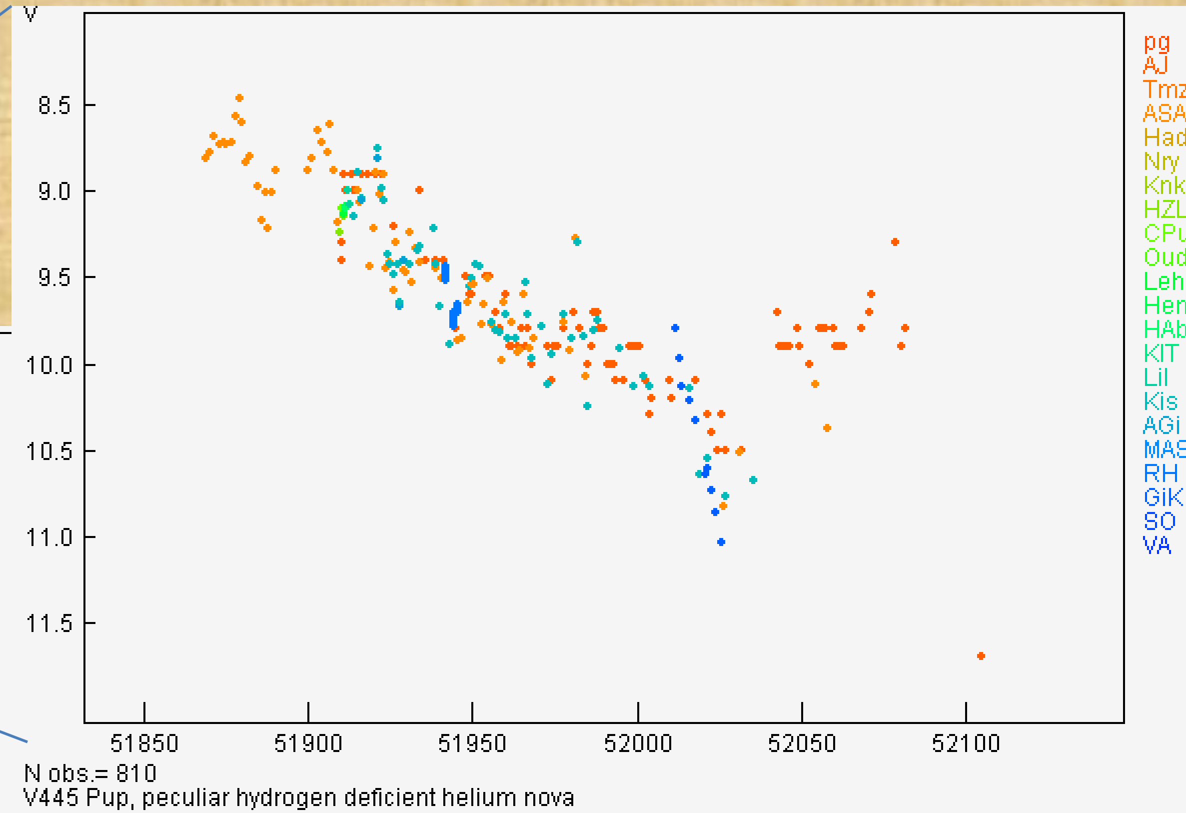
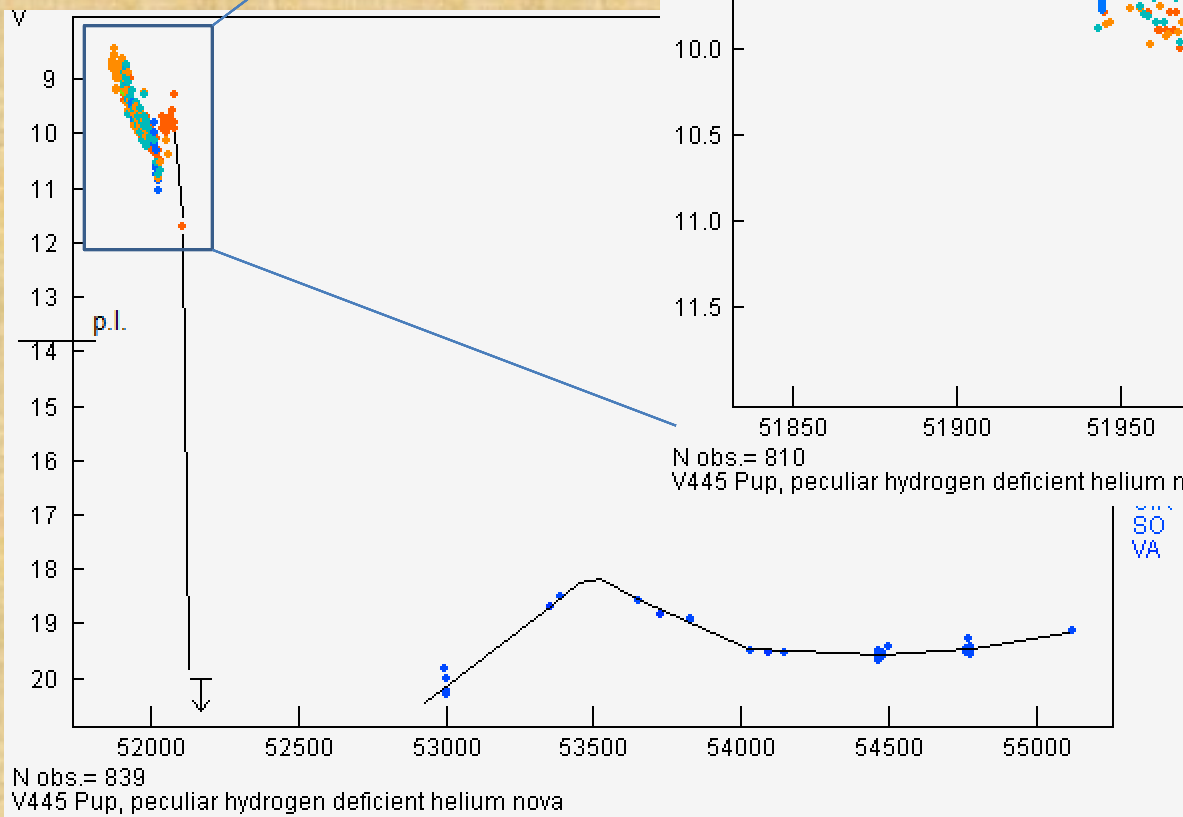
V445 Pup. Light curves

The unusual hydrogen-deficient nova appeared in Puppis in November 2000.



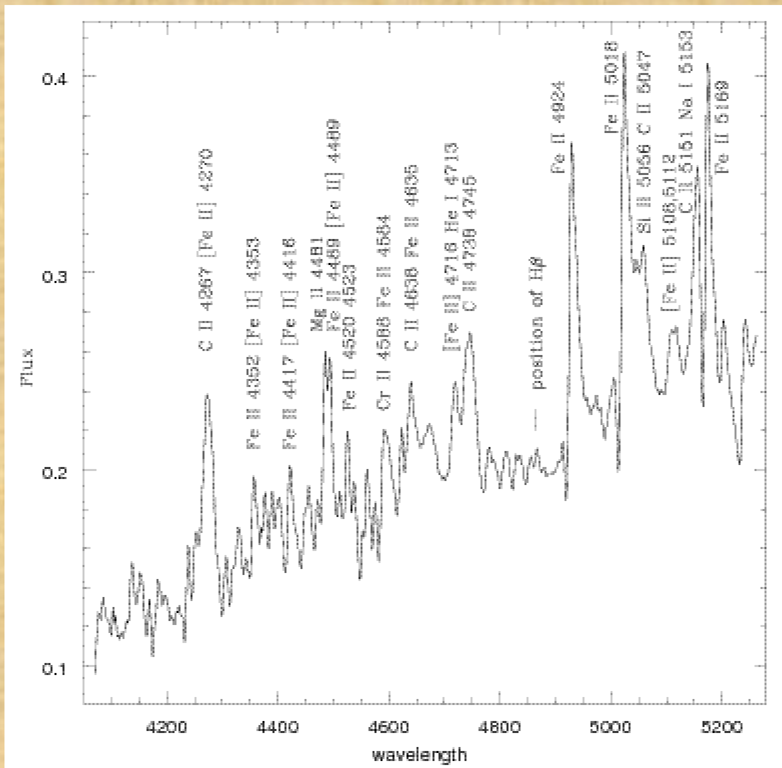
The V band light curve in outburst

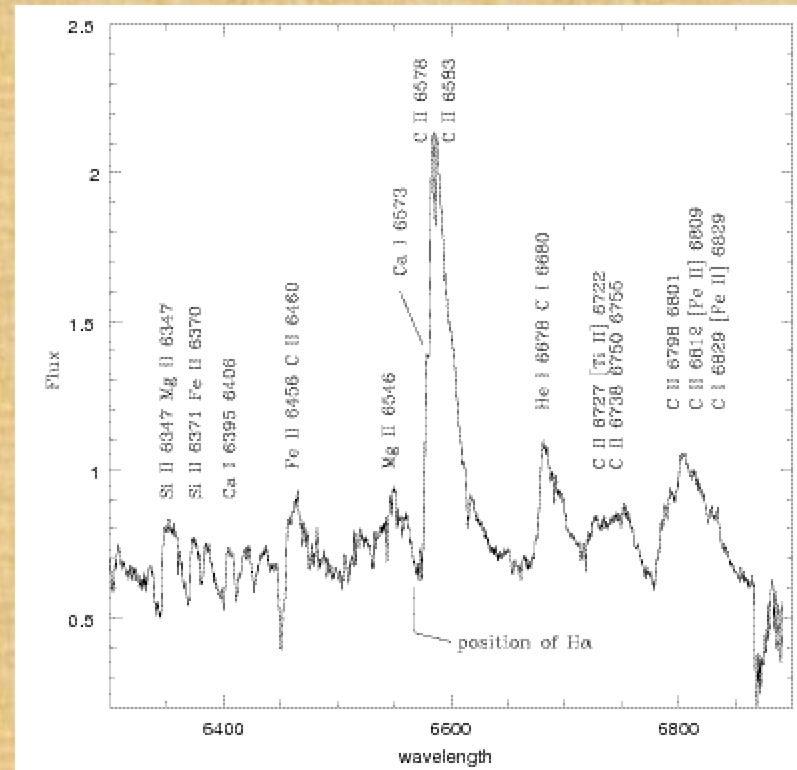


The V band light curve.
p.l. – pre-outburst level

V445 Pup. Spectroscopy in outburst

Iijima T. & Nakanishi H., 2008, AsAp 482, 865





Balmer emission lines typical of classical novae were not present in the spectrum. The spectra were dominated by emission lines arising from Fe II, Ca II, C II, Na I, O I.

V445 Pup as a candidate of the SN Ia precursor

V445 Pup is an unique helium nova which was predicted in theoretical works by Kato et al. (1989) and Iben & Tutukov (1994) who considered the case of a degenerate white dwarf accreting helium from a helium-reach donor.

As a result of helium burning on the surface of CO white dwarf, its mass gradually increases, and exceeds Chandrasekhar limit for the mass of a white dwarf, 1.4 $M_{\odot}$. And this is the cause of SN Ia explosion.

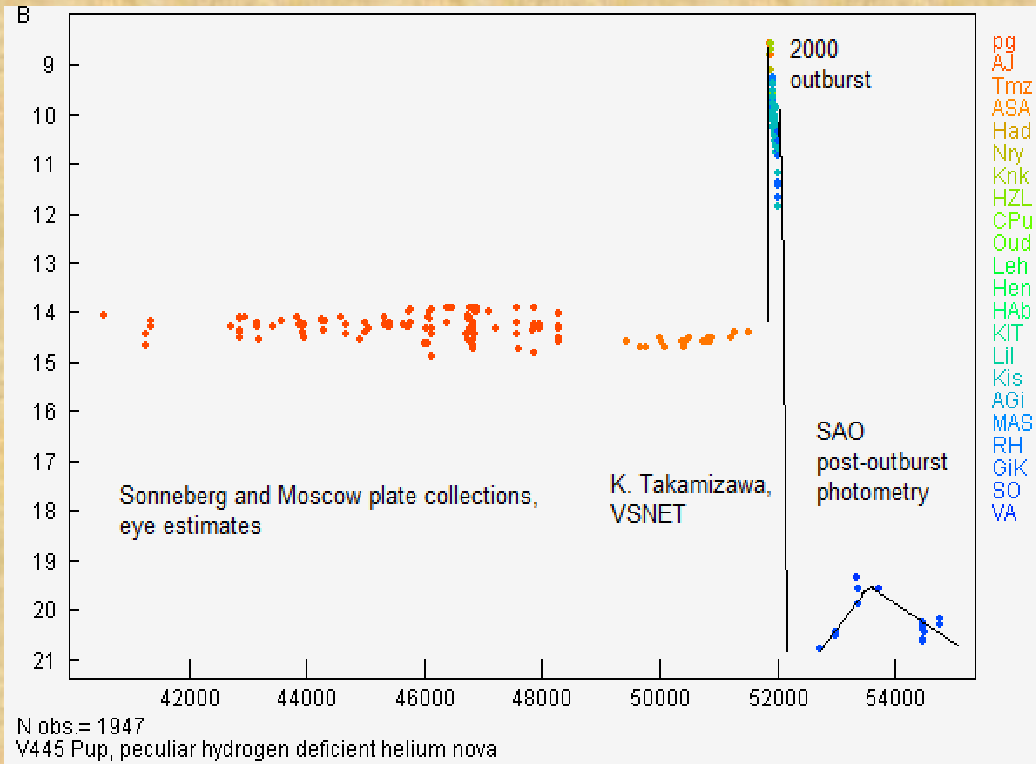
The light curve modeling by Kato et al. (2008) reveals that CO white dwarf in V445 Pup is very massive ($M_{WD} > 1.35M_{\odot}$), and half of accreted matter remained on the white dwarf after the outburst. Therefore, V445 Pup was considered a strong candidate for type Ia supernova precursor.

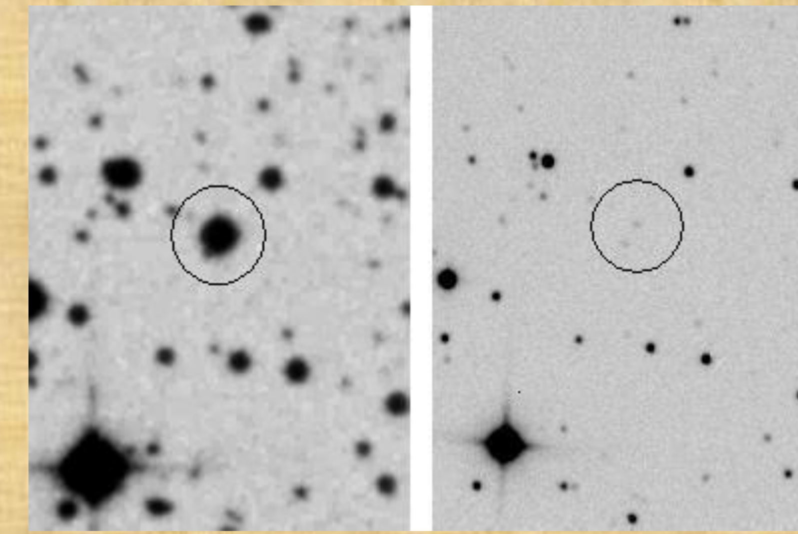
P. Woudt and D. Steeghs called V445 Pup a “ticking stellar time bomb” in ESO Science Press Release 0943.

References: Iben I. Jr., Tutukov A.V., 1994, ApJ 431, 264; Kato M., Saio H., Hachisu I., 1989, ApJ 340, 509; Kato M., Hachisu I., Kiyota S., Saio H., 2008 ApJ 684, 1366;

V445 Pup. Progenitor

The progenitor was about 300 times brighter than the remnant of the outburst.





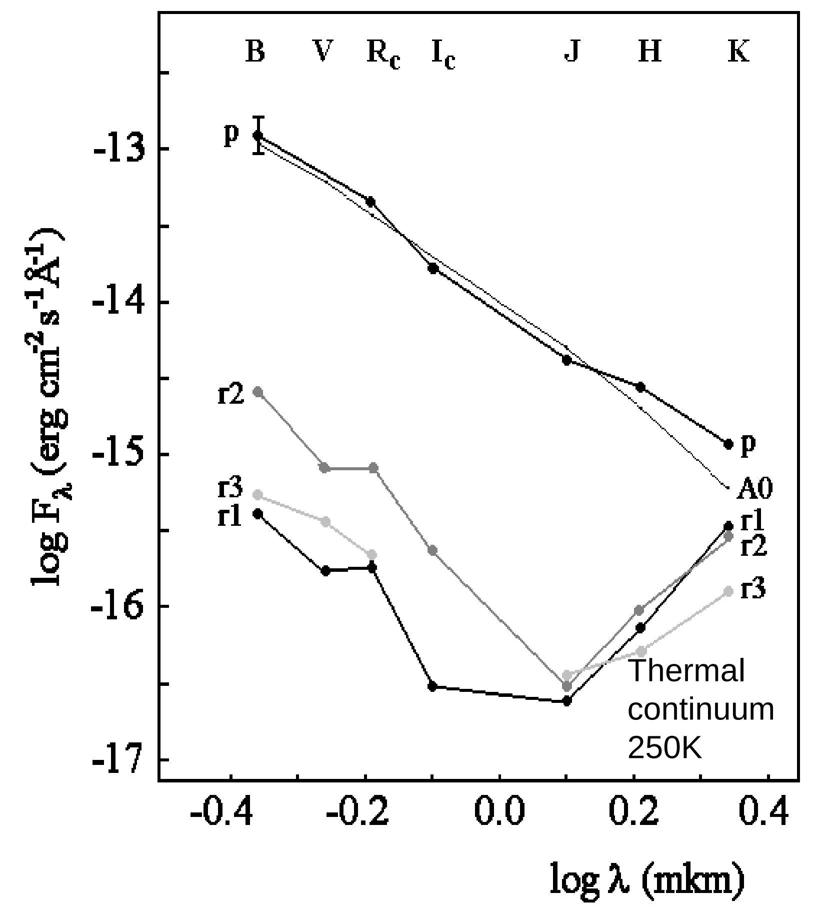
The B band light curve in the time range 1969 – 2008.

Images of V445 Pup:

left – progenitor’s image taken in 1986 December 8 with ESO Schmidt telescope in the R band;

right – remnant’s image taken in 2009 October 21 with SAO 1-m reflector

V445 Pup. Spectral energy distributions



p – progenitor;
A0 – A0 type star.
Bars in B band show the ranges of variability.

r1 – remnant on December 2003;
r2 – remnant on January 2005;
r3 – remnant on November 2008.
The remnant has emission-line optical spectrum, no continuum is seen in VLT spectra. BVRcIc magnitudes are formed by accidental hitting of line radiation into photometric bands.

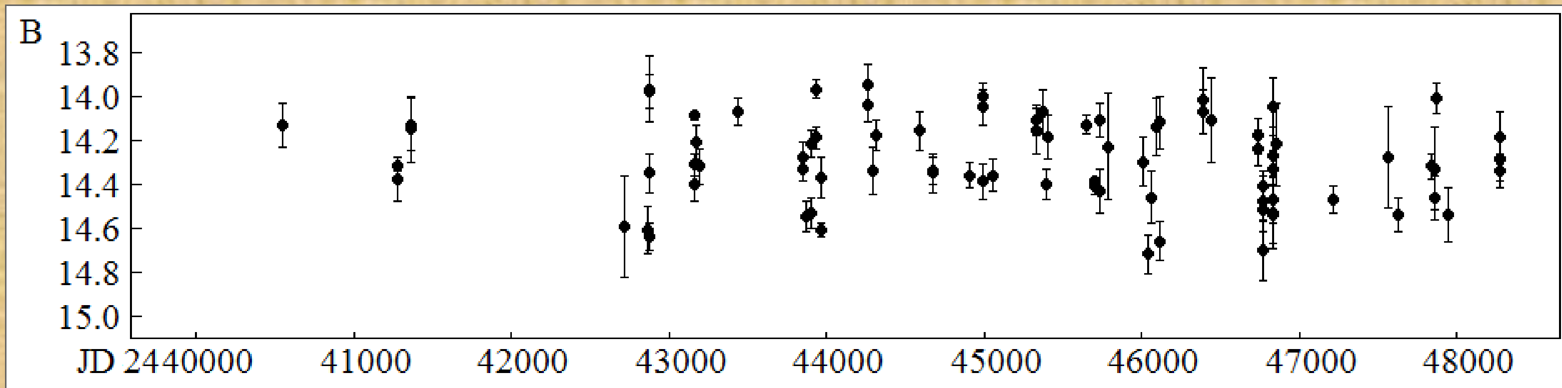
Interstellar extinction corresponding to E(B-V) = $0^m.51$ is taken into account.

The radiation of the remnant comes from a non-stellar object!

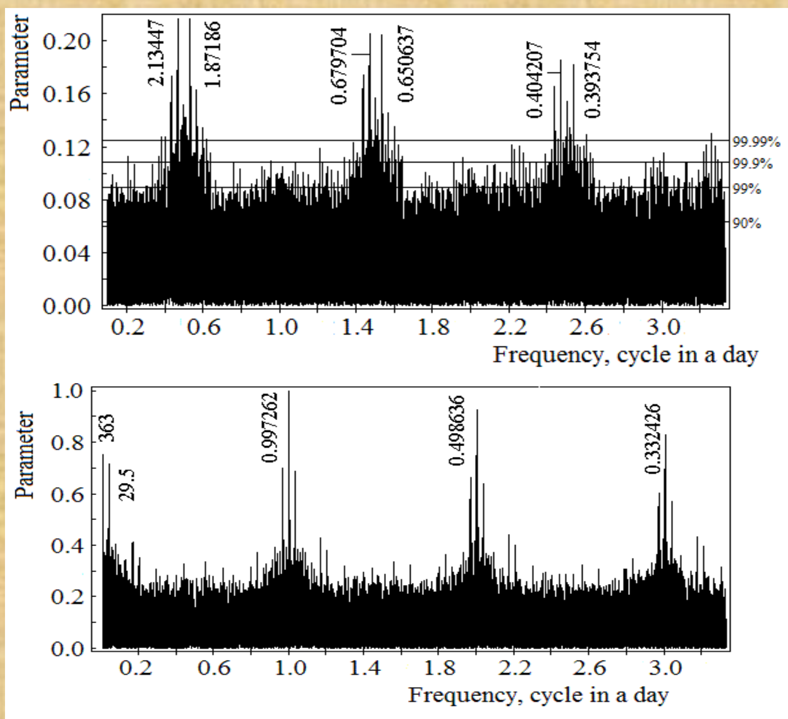
Reference: Woudt P.A., Steeghs D., Karowska M., Warner B., Groot P.J., Nelemans G., Roelofs G.H.A., Marsh T.R., et al., 2009, ApJ 706, 738

VLT + NAOS/CONICA image with the adaptive optics taken in K band on March 2007 (Woudt et al. 2009)

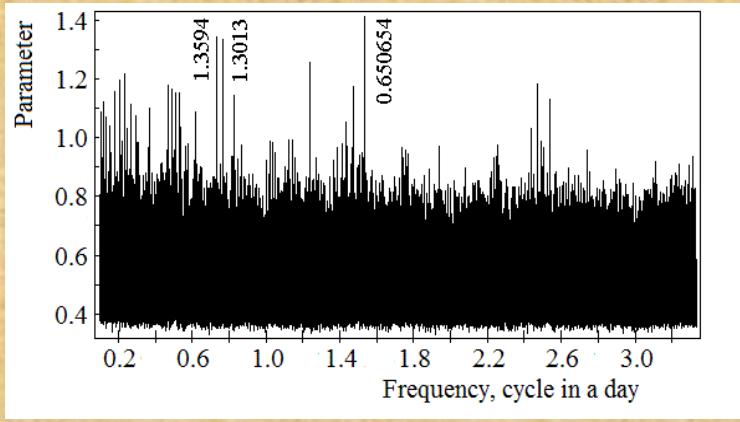
V445 Pup. Digitized photographic photometry



Photographic light curve of the progenitor based on the plates of Moscow and Sonneberg archives dated between 1969 and 1994. The star was evidently variable.



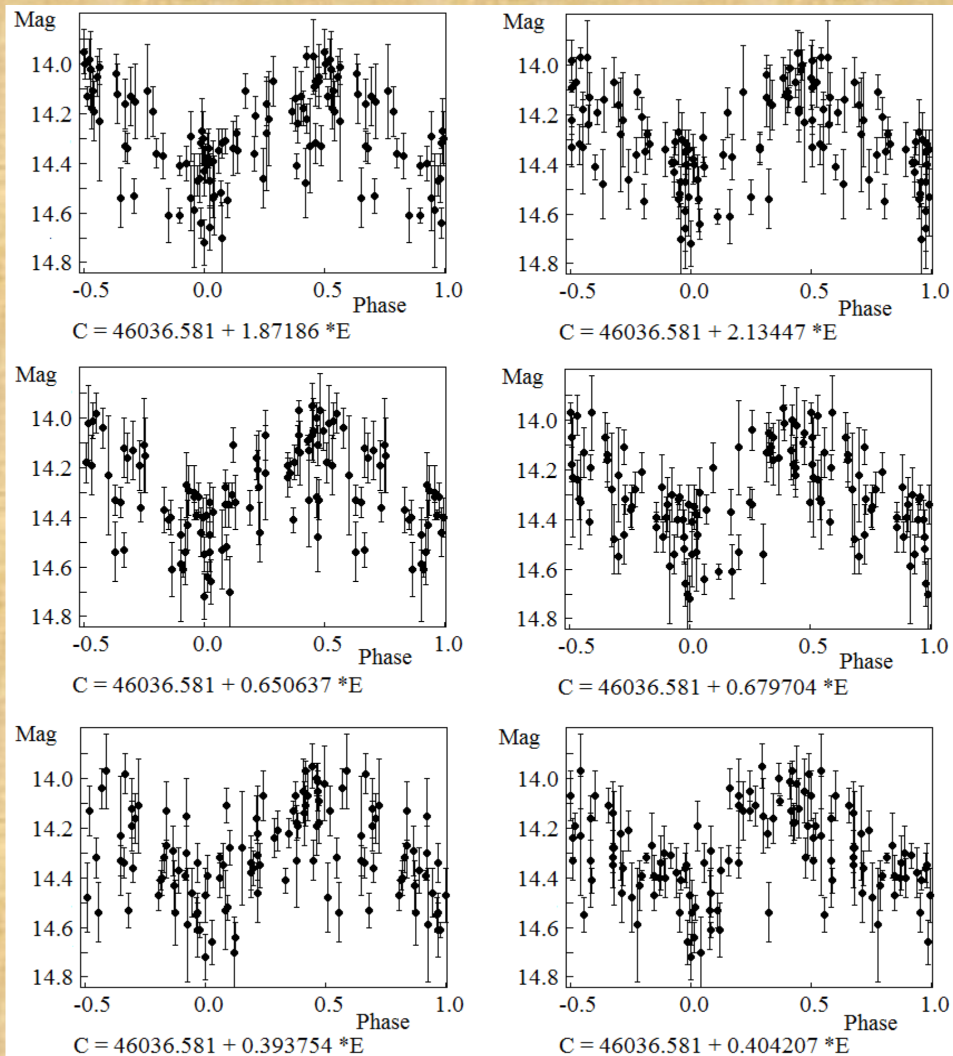
Deeming amplitude spectrum and spectrum of window



Lafler-Kinman periodogram. The variability was periodic.

V445 Pup. Light curves revealed by Deeming method

(descrete Fourier transform)



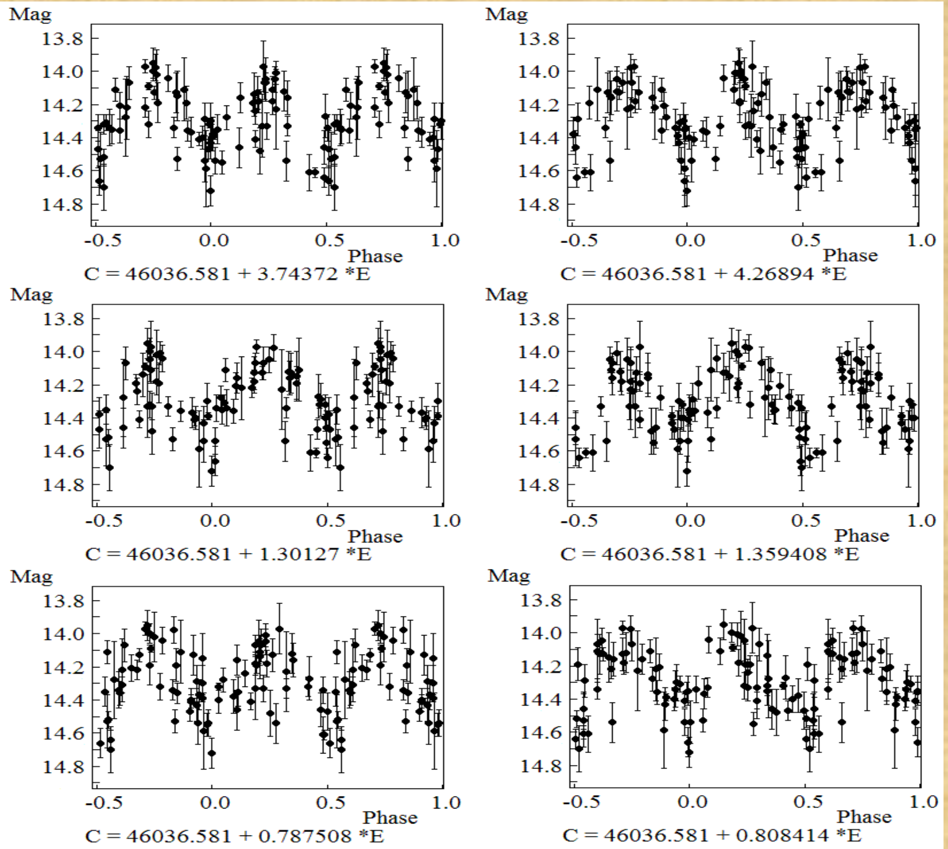
P	σ P	Parameter	f (c/d)	Remark
Deeming		*Ampl./2*		
$2^{\mathrm{d}}.134469$	$0^{\mathrm{d}}.00011$	$0^{\mathrm{m}}.217$	0.468501	f_0
1.871862	0.00009	0.217	0.534227	$1 - f_0$
0.679704	0.000012	0.205	1.471229	$1 + f_0$
0.650637	0.000011	0.204	1.536956	$2 - f_0$
0.404207	0.000004	0.185	2.473977	$2 + f_0$
0.393764	0.000004	0.182	2.539658	$3 - f_0$

The photographic half-amplitude of periodic component was $0^{\mathrm{m}}.2$.

*Heliocentric Julian dates are given without first two digits 24…

V445 Pup. Double-wave light curves with periods revealed by Deeming method

(descrete Fourier transform)

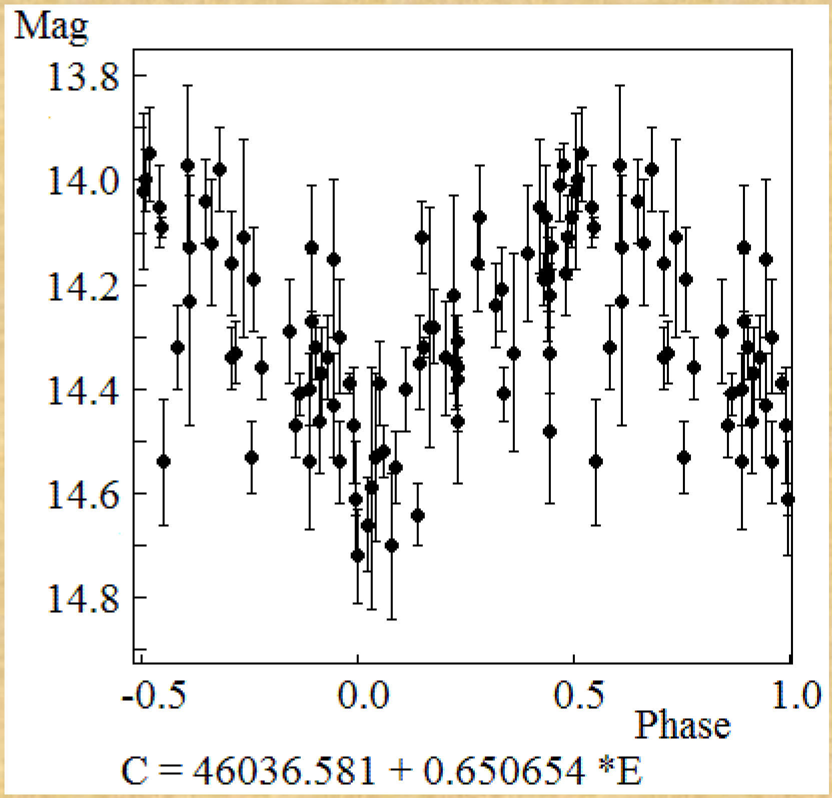


*Heliocentric Julian dates are given without first two digits 24…

We reject double-wave solutions because they need components with equal surface brightness. This assumption contradicts to the presence of CO WD in the system.

V445 Pup. The best light curve revealed by Lafler & Kinman method

(phase-dispersion minimization)



P	σP	Parameter	f (c/d)	Remark
L-K		θ		
0.650654	0.000011	0.718	1.536914	$2 - f_0$
1.359423	0.000048	0.734	0.735606	d.w.[a]
1.301269	0.000044	0.744	0.768481	d.w.
0.808410	0.000017	0.787	1.236996	d.w.
0.679686	0.000012	0.852	1.471269	$1 + f_0$
0.404207	0.000004	0.844	2.471214	$2 + f_0$

[a] double wave light curve

This solution was chosen as the most probable.

*Heliocentric Julian dates are given without first two digits 24…

We explain such a light curve by rotating common envelope binary with a bright spot on the surface of the common envelope.
This is not the reflection or the irradiation effect due to absence of an X-ray companion. The donor is hot for irradiation from white dwarf or sdO star.

Physical parameters of the progenitor

Distance	~ 5 kpc (3 – 6.5 kpc) *Iijima & Nakanishi (2008)*	8.2 kpc *Woudt et al. (2009)*
E(B-V)	0.51 mag	based on interstellar Na I D_2D_1 lines
M_V	-1.28	-2.36 -6.1 ± 0.09 *Woudt et al. (2009)*
Spectrum	A0	
Temperature	10000 K	
Bolometric correction	-0.25	
log (L / L⊙)	2.54	2.96 4.34 ± 0.36 *Woudt et al (2009)*
Absolute proper motion	0″.008 ± 0″.004 *Platais et al. (2001)*	
Radial velocity	+224 ± 8 km s^{-1} *Iijima & Nakanishi (2008)*	
Variability range	14.0 – 14.7 B	
Light elements	Min I = 2446036.581 +0^d.650654 E	

References: Iijima T. & Nakanishi H., 2008, AsAp 482, 865; Platais I., Kozhurina-Platais V., Zacharias M.I., Zacharias N., 2001, IAU Circ. 7556; Iijima T., Nakanishi H., 2008, AsAp 482, 865; Woudt P.A., Steeghs D., et al., 2009, ApJ 706, 738.

CONCLUSIONS

V445 Pup progenitor was an A0 type common envelope binary with a bright spot on its surface. Components of the binary were an evolved helium star lost its hydrogen envelope due to accretion, and a CO type white dwarf.

The system was not absorbed strongly by circumstellar dust. Only very weak near IR excess was seen in the energy distribution.

The shape of the light curve after the outburst suggests that there was a deep dust absorption minimum which finished in 2004.

The remnant of outburst has an extended structure, and its brightness is about 300 times fainter than the brightness of the progenitor. No star-like object was seen up today with adoptive optics. No reddened A0 type star is presented.

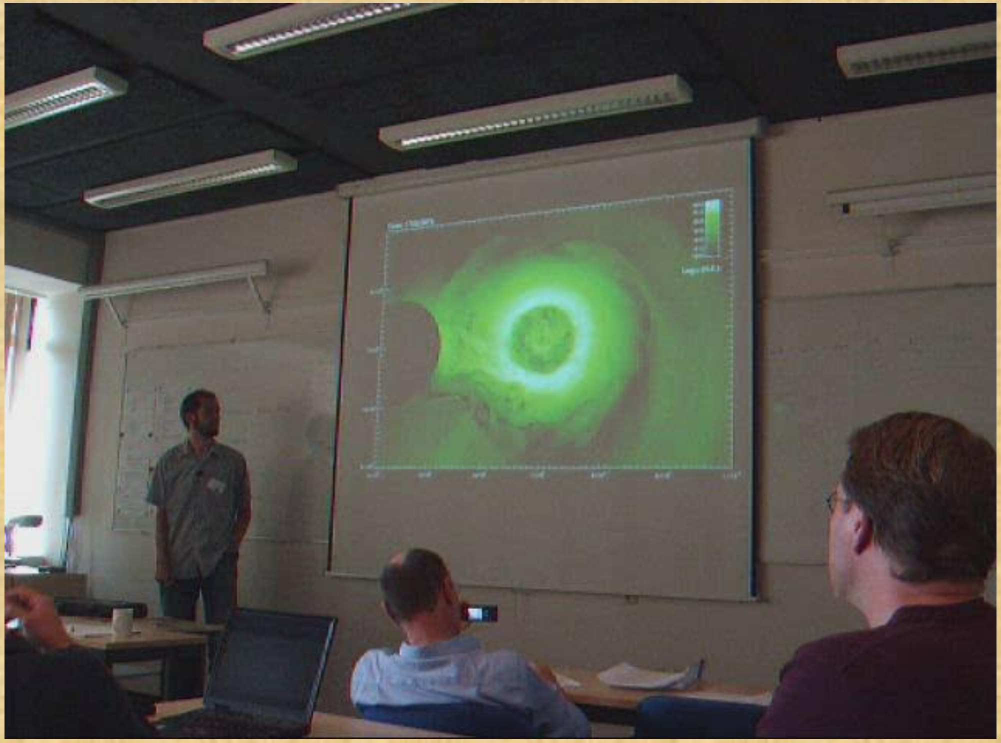
So, we concluded that the system and its components underwent strong destructions.

We suppose that helium flash was caused by merging of He rich nucleus of an evolved star with a CO white dwarf, and both the nucleus and the common envelope did not survive in the explosion.

CONCLUSIONS

Some observational details of V445 Pup outburst may be explained by the results of dynamical calculations by Guillochon et al.(2010) of merging event in the system with a pure He dwarf with a hybrid CO white dwarf. This modeling predicts CO white dwarf detonation due to He flash on its surface in some cases. CO white dwarf detonates due to focusing of shock wave of He flash inside its body.

We suppose that V445 Pup outburst is an event of double detonation described by Guillochon et al. (2010). Then the expanding and narrowly confined bipolar shell is the debris of destroyed white dwarf.



James Guillochon demonstrates his double detonation model at the Leiden Workshop “Stellar Mergers” held in September and October, 2009.

Reference: J. Guillochon, M. Dan, E. Ramirez-Puiz, S. Rosswog, 2010, ApJ 709, L64

CONCLUSION

Scenario of SN Ia will not take place in V445 Pup system if at least one of the following events really happened in 2000 - 2001 outburst:

(1) Helium donor was accreted on the white dwarf and it was destroyed in the helium flash;
(2) CO white dwarf detonated and most part of its mass was dispersed into space.

THANK YOU