Structure of circumstellar matter in helium nova V445 Puppis and its time evolution

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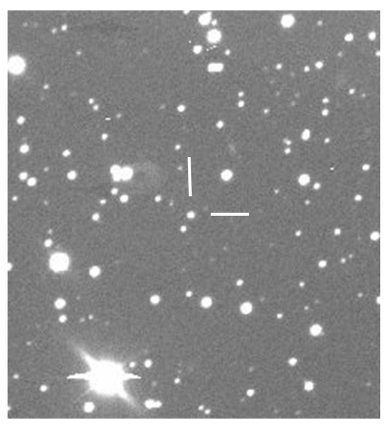
V445 Pup (Nova Puppis 2000) is known as the first helium nova. Its stellar system would consist of a massive white dwarf and a helium star, and could be a strong candidate for a Type Ia supernova progenitor.
To explore the structure of the stellar system and its evolutional stage, we performed optical and near-infrared observations, including one epoch Subaru/FOCAS photometry and spectroscopy. Our spectropolarimetry during the outburst stage suggests that the bipolar outflow found by near-infrared AO imaging >4 years after the outburst already blew even at the outburst phase and that there were pre-existing scattering clouds along the circumstellar disk only the earliest stage of the outburst. The optical spectrum at 11 years is dominated by [O III], [O II] and He I lines, suggesting the hydrogen-poor circumstellar matter ionized by the nova remnant is seen and the possible helium star is obscured. At 18 years, the optical and near-infrared light is still about 3 mag fainter than that before explosion, but, in recent 3 years, the optical light is gradually brightening while the near-infrared light is almost stable or slightly faded, which cannot be explained by a simple clear up of the dusty circumstellar matter.

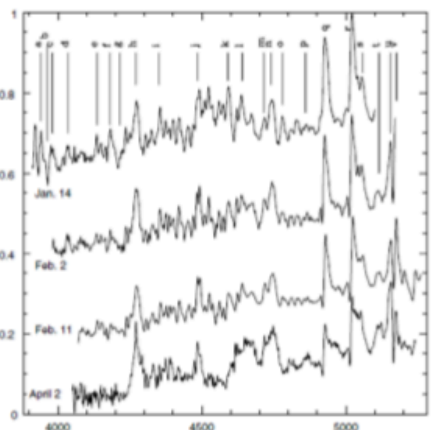
Intro of V445 Puppis

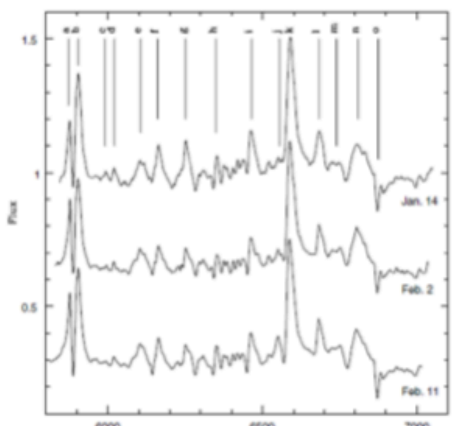
V445 Puppis・・・Classical nova (first helium nova) brightened in December 2000
It is considered to be the origin of type Ia supernovae by Optically thick wind theory(Kato et al (2008))

Images V445 Puppis
(Taken with HOWPol (Kanata))



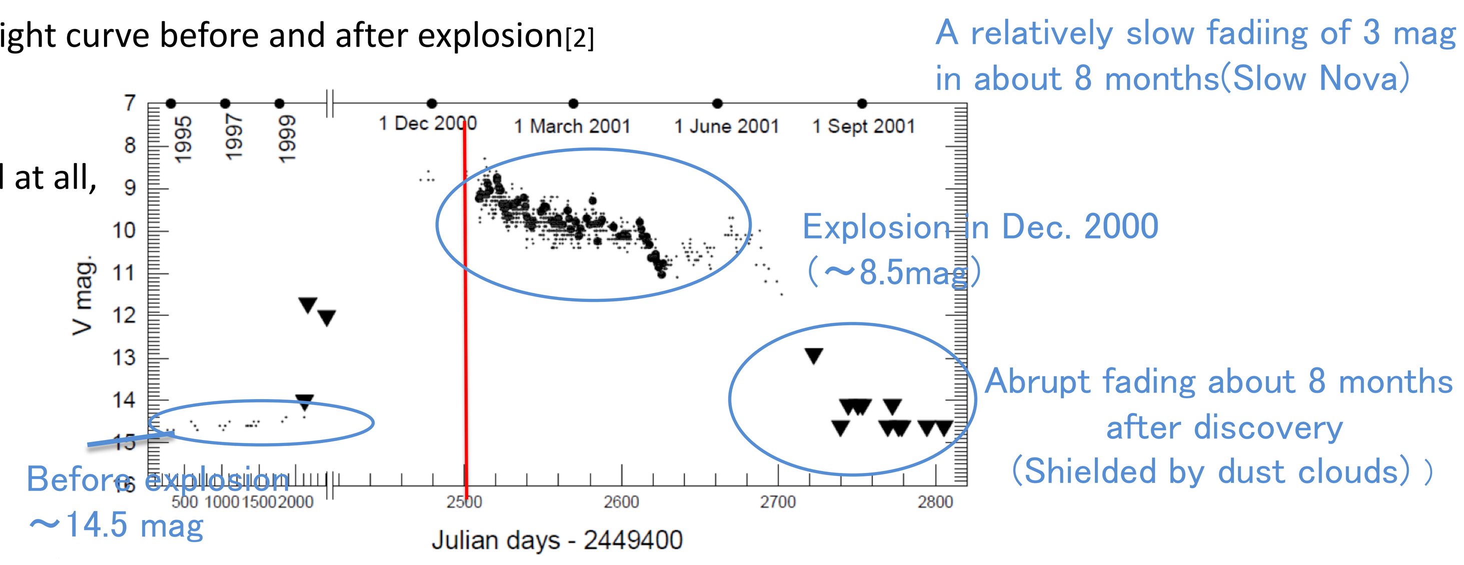
Medium dispersion spectrum acquired during the fading period after the explosion[1]



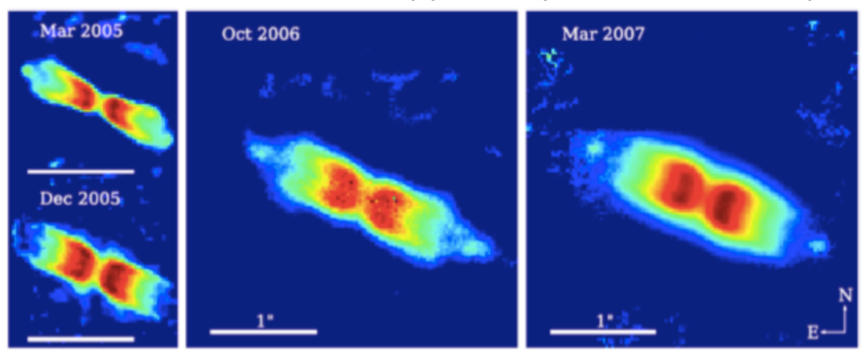


Hydrogen emission lines were not detected at all, and a lot of helium was detected
=>This is considered helium nova
(First example of helium nova)
=>Not yet confirmed by observation

Light curve before and after explosion[2]



Wind observed in V445 Puppis 4-6 years after the explosion[4]



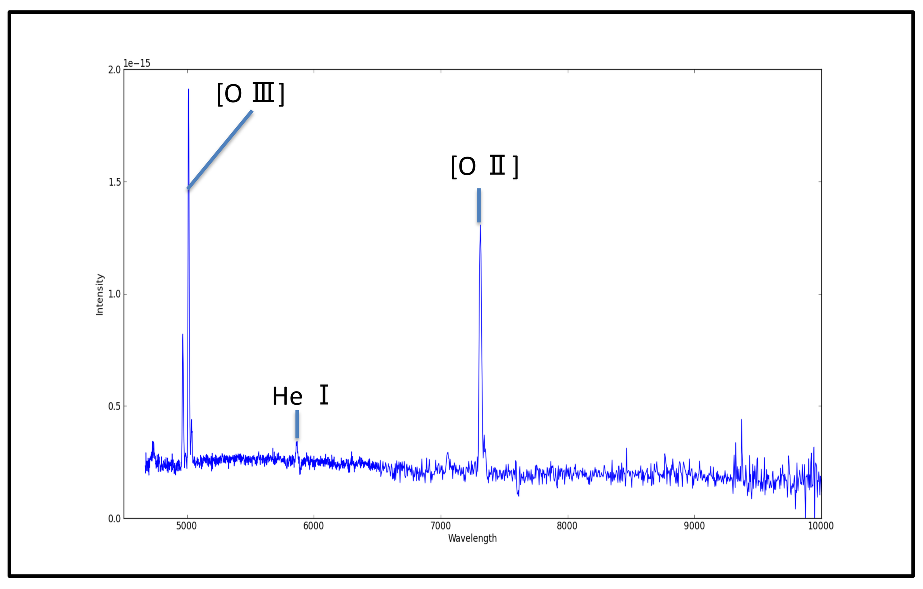
VLT telescope (Woudt et al. (2009))showed extreme dipolar winds along the 66° axis from north to east.
the velocity of wind is $6720 \pm 250 km/s$

Purpose

V445 Pup, the only helium nova, will observe visible polarization spectroscopy during the explosion period and continue to observe visible infrared light during the quiet period.
=>The validity of the evolution model will be verified by investigating the distribution of stars and their temporal evolution and the presence of helium companions.

Late time: Spectroscopy in 2012

photometric spectroscopic observations were performed with the Subaru Telescope during the quiet period of explosion (2012).



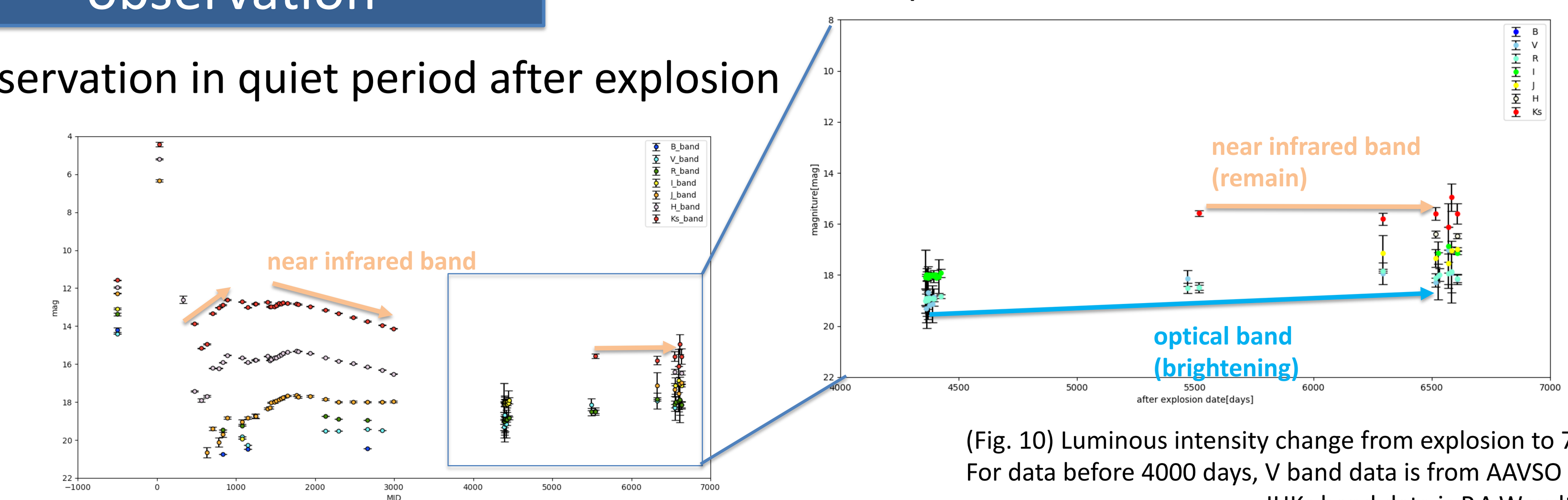
Subaru + FOCAS 2012/10/23.5（UT）
Photometry: B:50ec V:30sec R:20sec: I:20sec
Spectroscopy: 0.8"slit,
B300 grism + no filter: 450sec
R300 grism + O58 filter: 450sec

・Forbidden lines of oxygen and emission lines of helium are outstanding
・No hydrogen emission line
・The absorption line is almost invisible,
=>binary system has a low-density, high-temperature region.

Result in long term observation

Photometric observations were made using the HOWPol and HONIR with Kanata telescopes from 2012 to 2018.

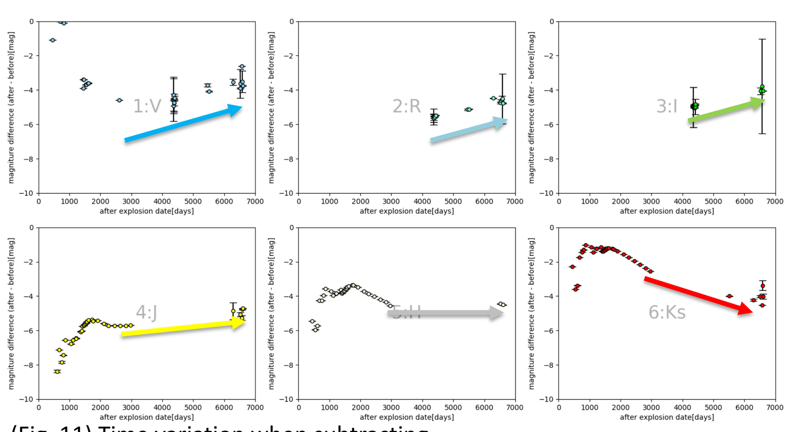
Observation in quiet period after explosion



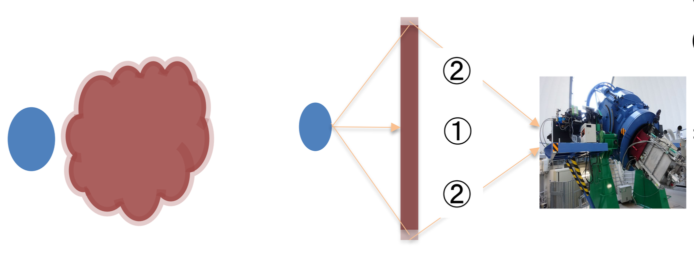
(Fig. 10) Luminous intensity change from explosion to 7000 days
For data before 4000 days, V band data is from AAVSO [5]
JHKs band data is P.A.Woudt et al (2009) [4]
After 4000 days, we used data acquired by HOWPol and HONIR of the Kanata telescope.

Comparison with before and after explosion grades for each wavelength

・optical band・・・(4000~7000days) A brightening trend is seen
・near infrared band ・・・(1000~2000days) A brightening trend is seen
(2000days~) after faded,
no light increase or decrease
・Darker than before explosion at any wavelength
(V band :14.5 mag(before explosion) => 18.15 mag(2019/02/01))
Comparison of magnitude difference before and after explosion
=> We can see the amount of light loss caused by dust from a classic nova
In recent years,
・brightening in the optical band
・no extreme increase or decrease in the near infrared band.
=>Cannot explained by a model in simple clearing of a normal dust cloud.
=> A model as shown in Fig. 12 was considered.



(Fig. 11) Time variation when subtracting (mag after explosion) - (mag before explosion) for each wavelength



(Fig. 12) Image of dust cloud and binary system
(left) front view (right) side view

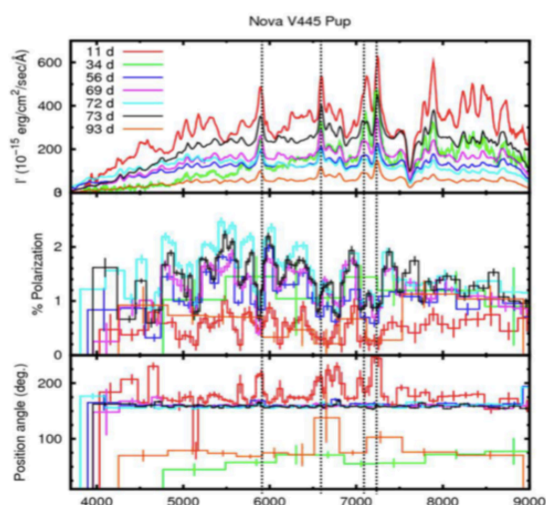
① Direct light from the classic nova is blocked by the thick part of the dust cloud
② Light passing through the thin part of the edge of the dust cloud is scattered and reaches the observer
=> Optical light and near-infrared light are reduced to the same extent
the optical light seems to increase with time,
not because the dust cloud becomes thinner from the outside,
Dark part seems to contract toward the center of the star with time.
(Scattering is likely to occur on the short wavelength side)

⇒Scattering is occurring at the edge of the dust,
there is a possibility of seeing polarized light by performing polarization observation

Outburst phase: Spectropolarimetry in 2002

Okayama Astrophysical Observatory (OAO) 0.91m telescope and 1.88m telescope equipped with visible low dispersion polarization spectrometer (HBS)

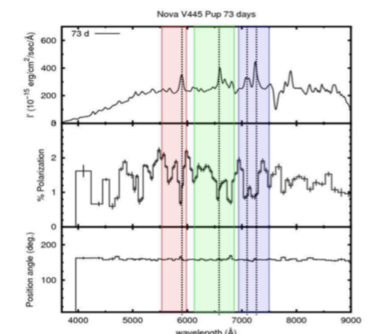
Estimating interstellar polarization

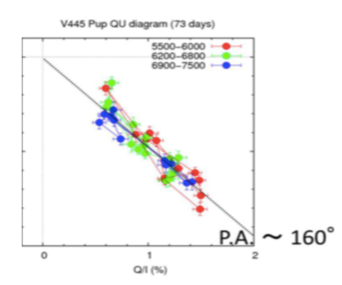


Continuous line: radiation from an optically thick part near the nova center
=> Interstellar polarization and nova-specific polarization are related
Emission line: stellar wind from nova (optically thin part)
=> Only interstellar polarization is relevant
=> Estimate interstellar polarization
by separating continuous light and emission line part

-Cut the area around the emission line for the 73rd day data.
(This time 5500-6000, 6200-6800, 6900-7500Å was selected)

-Check how it moves on the QU plane when changing the wavelength within the wavelength range.

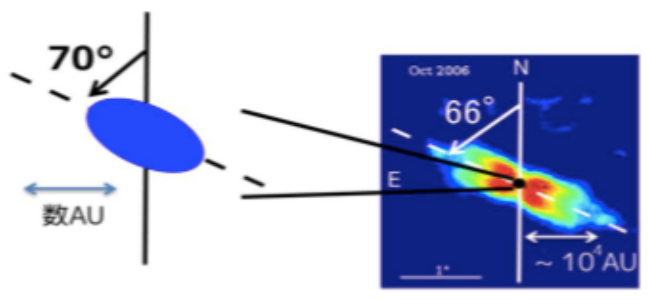




Estimated
Interstellar polarization degree 0.6%
polarization angle θ = 160 °
=> Same as surrounding interstellar polarization

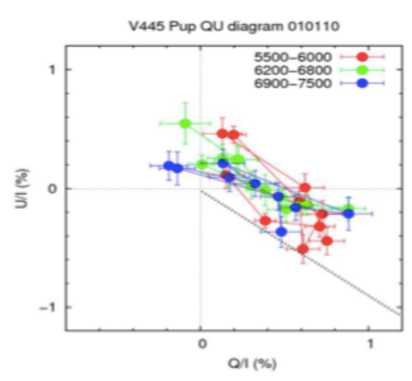
(left Fig.) Emission lines used for interstellar polarization
(red : 5500-6000Å)
(green: 6200-6800Å)
(blue: 6900-7500Å)
(right Fig.)Q-U plane of 73 days

Estimating interstellar structure after explosion



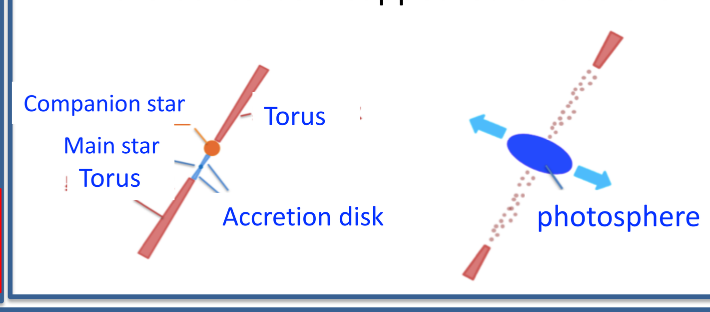
Interstellar polarization and nova-specific polarization
... 1.3%, θ = 160 °
=> Polarization specific to nova ... 0.7%, θ = 160 °
The polarization of the continuous line component
is scattered light from the nova pseudosphere.
=> Artificial photosphere suggests a flat shape from north to θ = 70 °
(In consistent with the direction of flattening
in Woudt et al. (2009) [4])

=> Suggests the existence of a flat artificial photosphere as the cause of extreme bipolar wind



The degree of polarization estimated by interstellar polarization appears to shift in the direction of θ = 160° to 60°

⇒Substance that scatters the continuous line component and the emission line component in the same direction exists in the direction of 150 ° from the north.
=> Equator direction of a white dwarf
=> Due to the outer star torus
=> Toroidal torus disappeared due to the wind after the 11th day



Estimate interstellar structure
(left image) before explosion
(right image)after explosion

Summary and future work

Summary
・Polarization spectroscopy observations immediately after the explosion.
=>The direction of the long axis coincides with the direction of the bipolar flow found in later AO observations.
・The difference between the luminous intensity before explosion and the recent is almost the same between optical and near infrared
=>Could not explain by simple dust clearing, and thought that scattering was observed at the edge of the dust cloud.
Future work
・Polarimetric observation may distinguish whether the scattered light is dominant
・In the scattered light component, the hint of the helium companion stars may exist.
=> Polarimetry (by FOCAS) could be powerful probe to distinguish it.

reference

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[6] Mason C.G. et al. 1997, The Astrophysical journal,494:783-791
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