The helium nova V445 Puppis

Outline:

- **The first observed helium nova**
- **Theoretical context: nature of underlying binary**
- **The distance to V445 Puppis: expansion parallax**
- **Constraints on the nature of the secondary**

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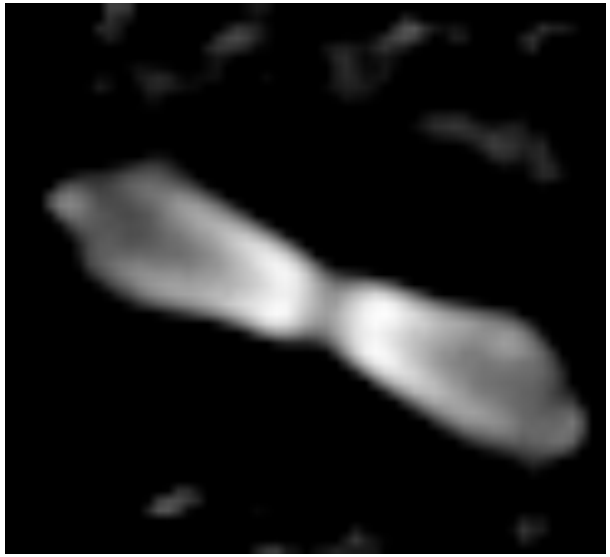
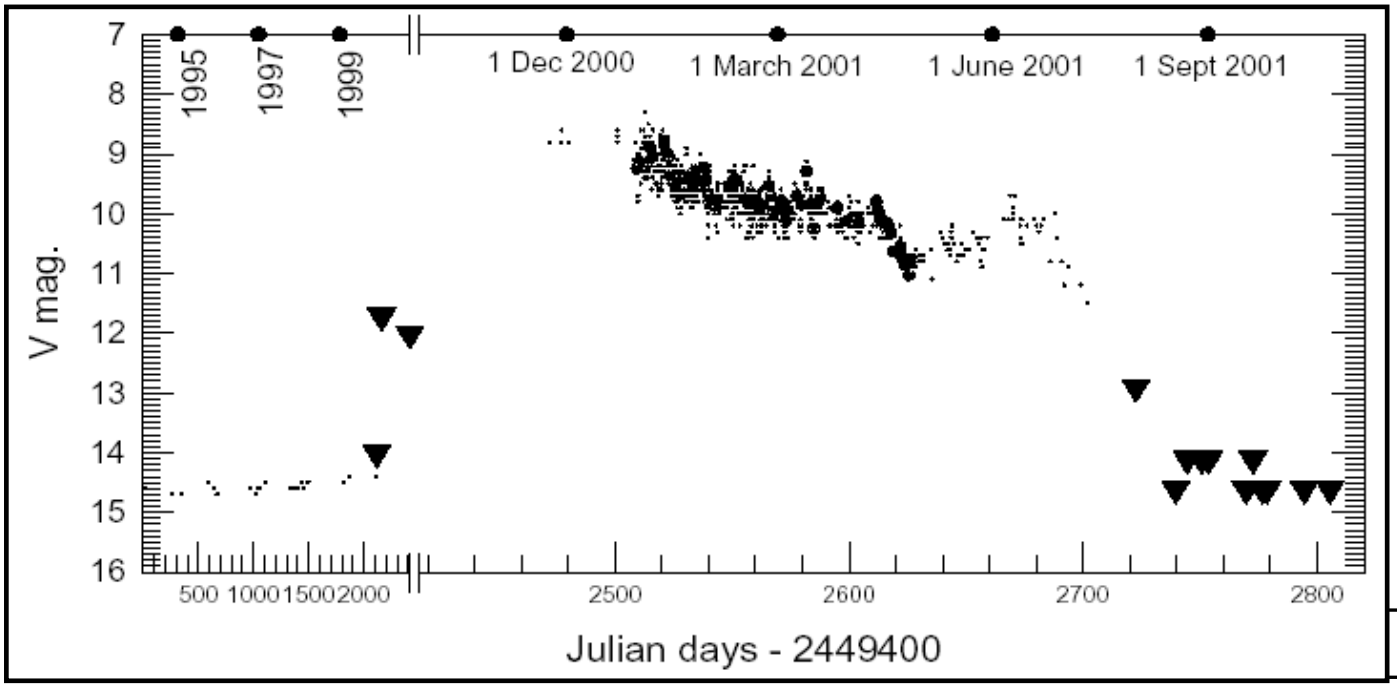


The first observed helium nova
the outburst

- Last nova of the previous millenium
- Outburst between September and 28 November 2000 (HJD 2451876)
- Slow nova (outburst lasted ~7 months)

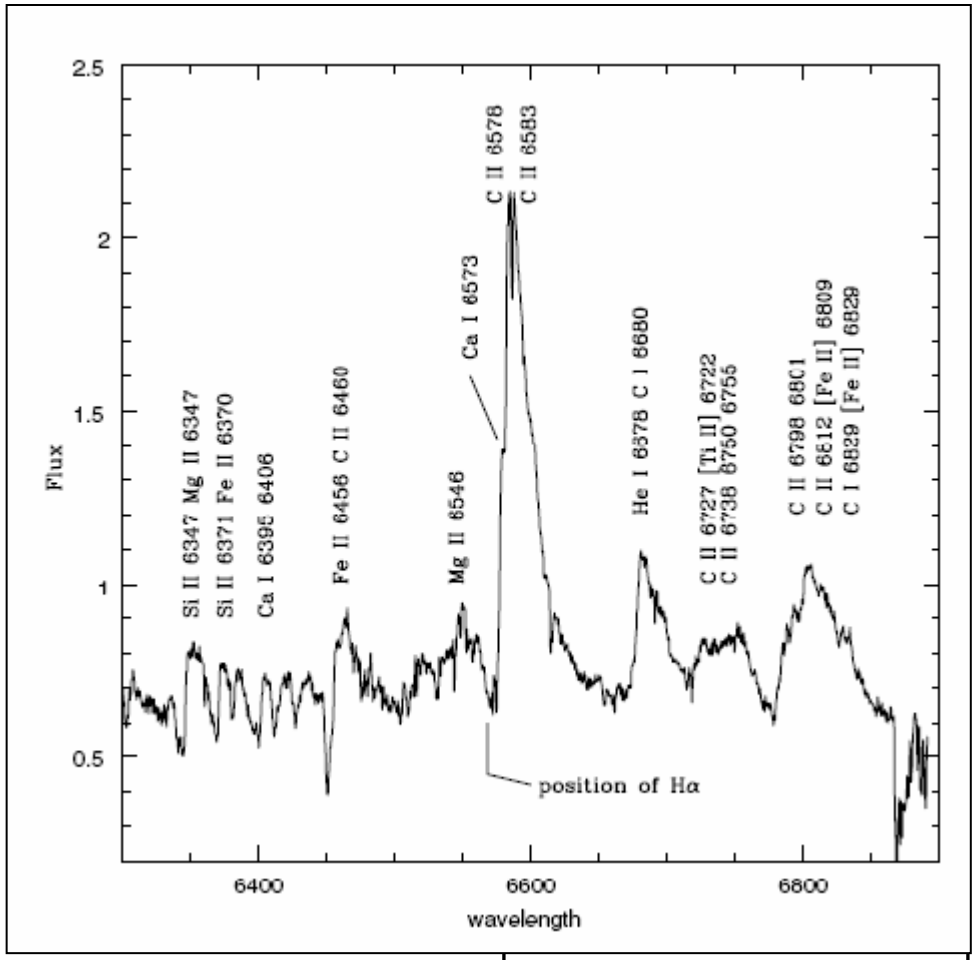


Ashok & Banerjee (2003)

The first observed helium nova
the absence of hydrogen (I)

Optical and near-infrared spectra during outburst are hydrogen-deficient and rich in helium and carbon.

No sign of Balmer lines in optical spectra (Iijima & Nakanishi 2008) nor Paschen/Brackett lines in NIR spectra.



Iijima & Nakanishi (2008)

The first observed helium nova
outflow during the outburst

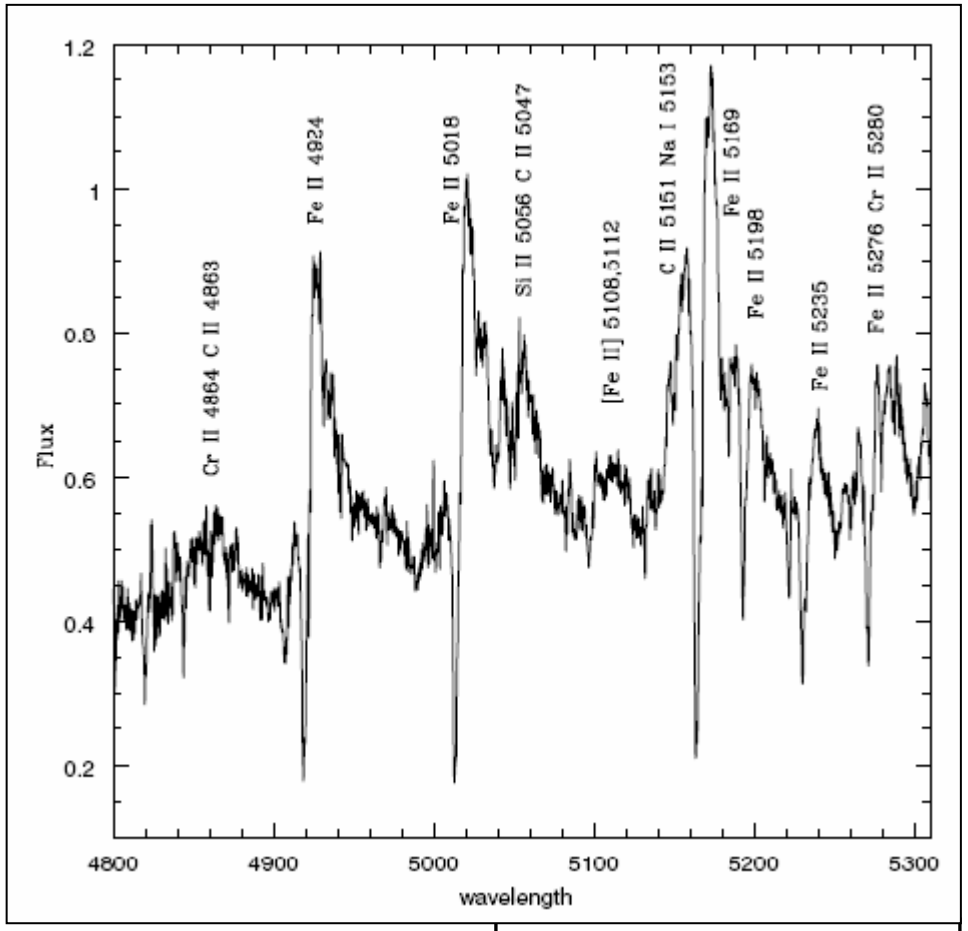
Heliocentric velocity:
+224 ± 8 km/s

Outflow velocity from blueshifted P Cygni profiles (Iijima & Nakanishi 2008): outflow ~ 500 km/s

P Cygni profiles on 29 March 2001 (λ/Δλ ~ 3500) (Howell et al. 2001): Terminal velocity -600 km/s, sharp absorption profile with FWHM ~ 130 km/s.
outflow ~ 600-700 km/s

Wagner et al. (2001): maximum expansion velocity ~ 900 km/s

3 February 2001 (λ/Δλ~4000)



Iijima & Nakanishi (2008)

Helium novae
a theoretical context (I)

Helium novae in AM CVn systems (Bildsten et al. 2007)
CO WD + non-burning He donor (WD)

Systems with short orbital periods (~4-5 min) evolving to longer periods (lowering of Mdot) results in unstable He burning via recurrent He shell flashes

Last flash (wider orbit, lower Mdot, higher M_{ign}) = .Ia supernova

Predicted rates of He nova: 1 every 250 years (Bildsten 2008)
for a 10^{11} M_{Sun} population of old stars.

See also Gijs Nelemans' talk yesterday

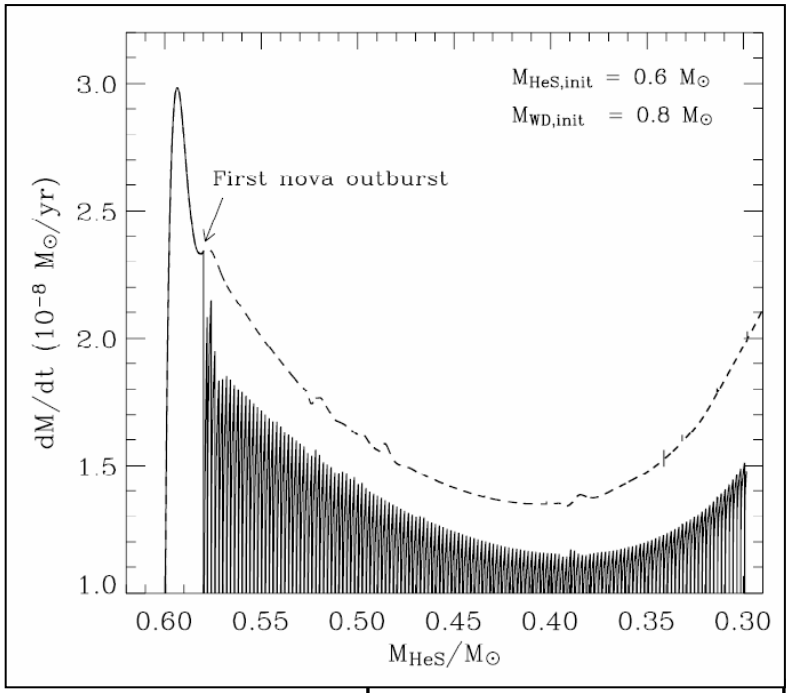
Helium novae
a theoretical context (II)

Helium novae in rotating CO WD + He star (Yoon & Langer 2004)

rotating CO WD (0.6 – 0.8 M_{Sun}) + He star (0.6 M_{Sun})

Recurrent weak He flashes under the following conditions:
After ΔM_{He} = 0.002 M_{Sun} (first ΔM_{He} factor 10 larger) and Mdot of few x 10^{-8} M_{Sun}/year.

In the above configuration, ~180 He nova flashes are expected (repeating time scale ~1.5 x 10^5 years). He star loses mass, evolves into WD and resembles AM CVn system.



Yoon & Langer (2004)

See also Lev Yungelson's talk on Wednesday

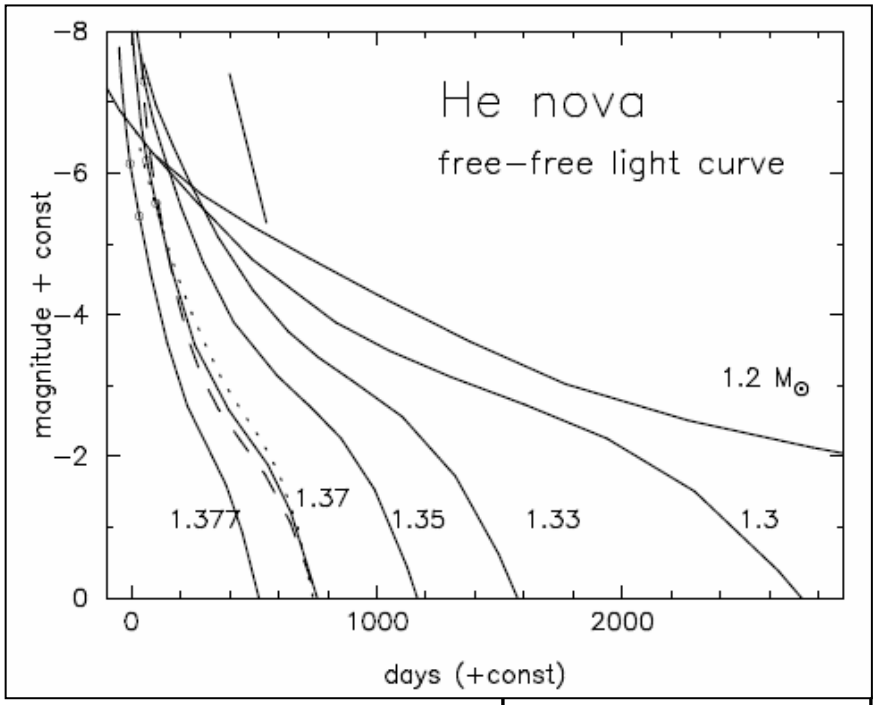
Helium novae
V445 Puppis – outburst modeling

Helium novae on massive WD (Kato et al. 2008)

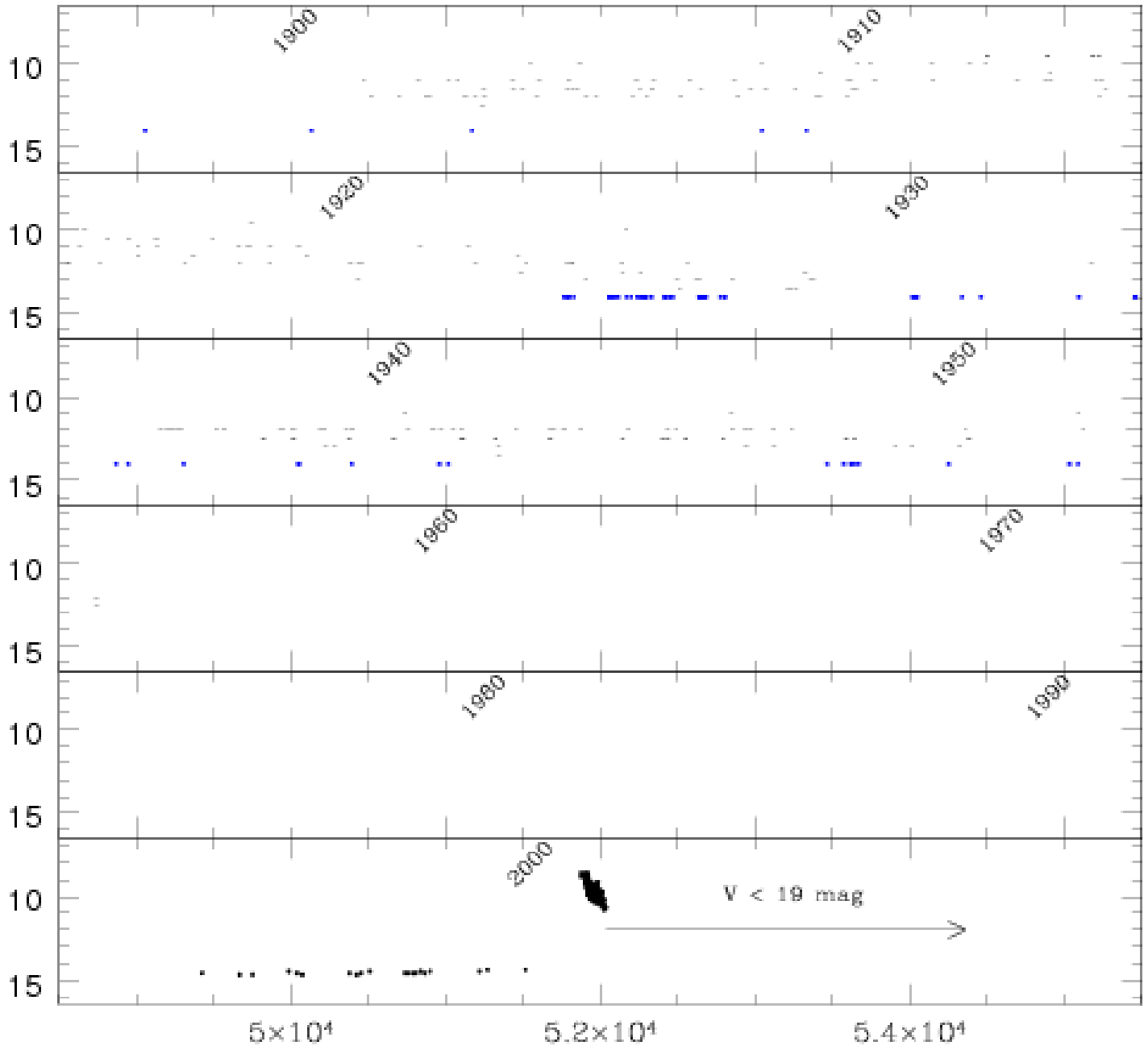
massive CO WD (> 1.35 M_{Sun}) + slightly evolved He star (> 0.8 M_{Sun})

Outburst light curve modeled by free-free emission. Suggestive of massive white dwarf (model dependent).

Supernova Ia progenitor via single degenerate channel (with helium donor)



Kato et al. (2008)


1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
10
15
V < 19 mag
5×10⁴
5.2×10⁴
5.4×10⁴

Helium novae
V445 Puppis: underlying binary

What can we say about the nature of the underlying binary of V445 Puppis?

WD + WD?

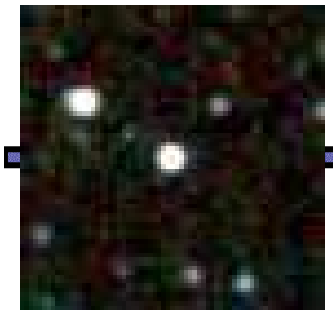
WD + He star?

massive WD + (massive) He star? SN Ia progenitor?

- ✓ Pre-outburst luminosity
  optical (V) + near infrared (2MASS) archival observations
  distance?

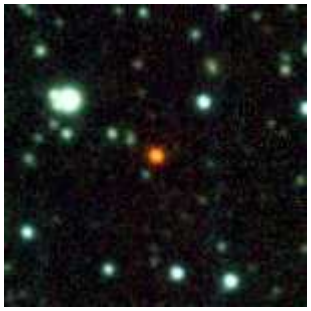
- ✓ Orbital period
  nothing known pre-outburst; impossible to obtain until dust clears

The first observed helium nova
post-outburst observations



02/02/99 2MASS pre-outburst

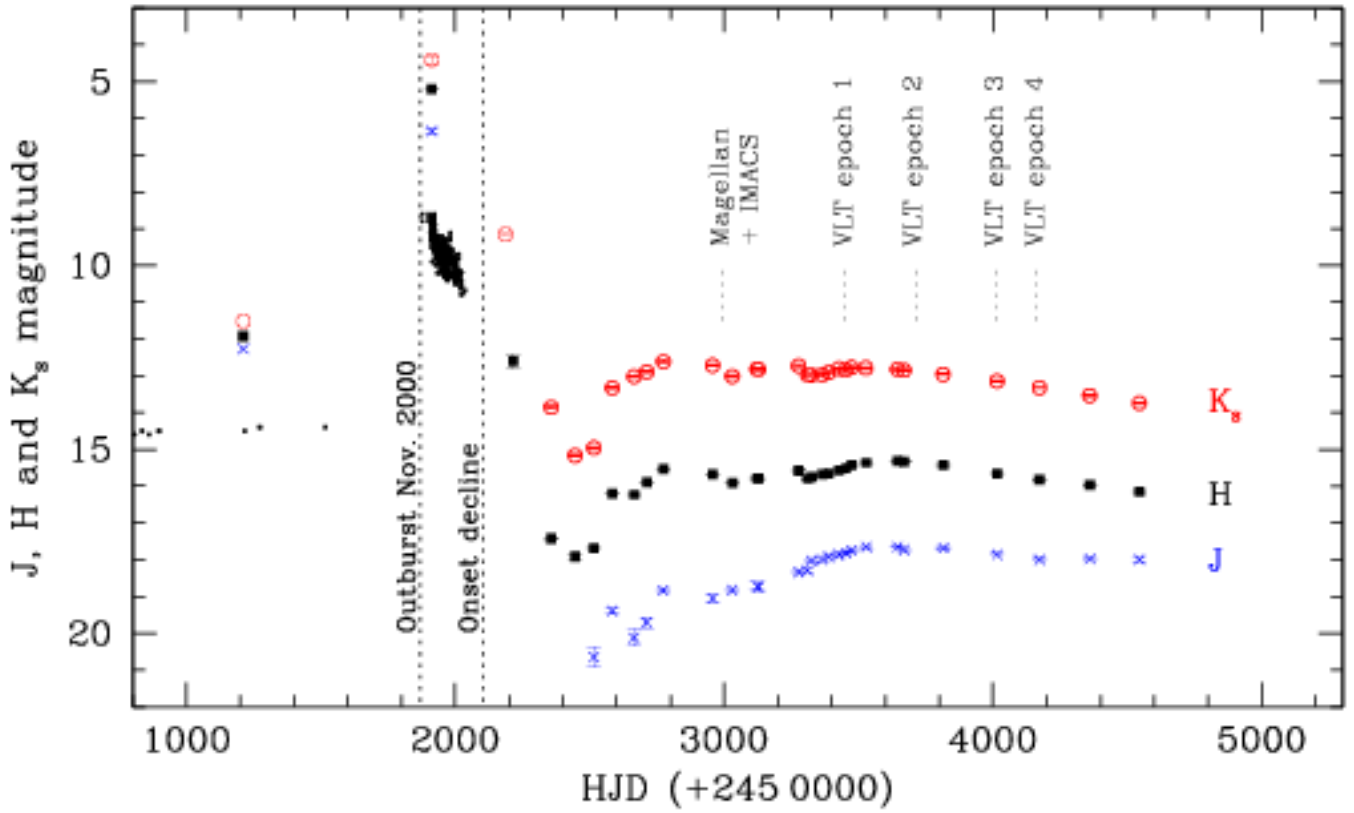
22/03/02 IRSF



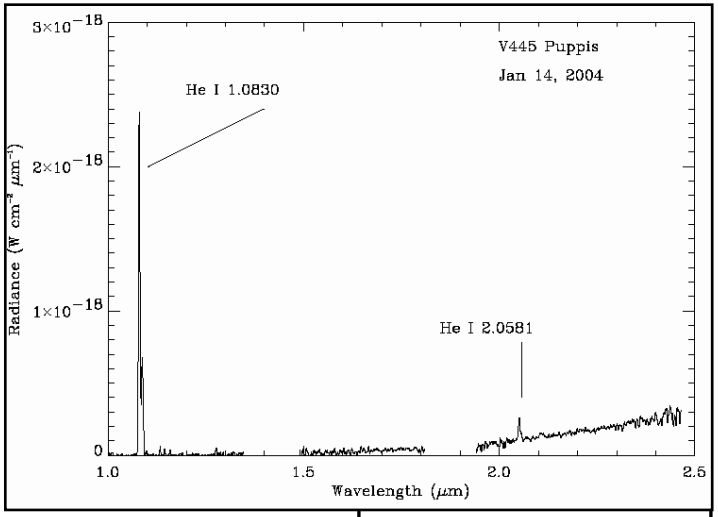
26/04/04 IRSF

NIR photometry with the InfraRed Survey Facility (IRSF)

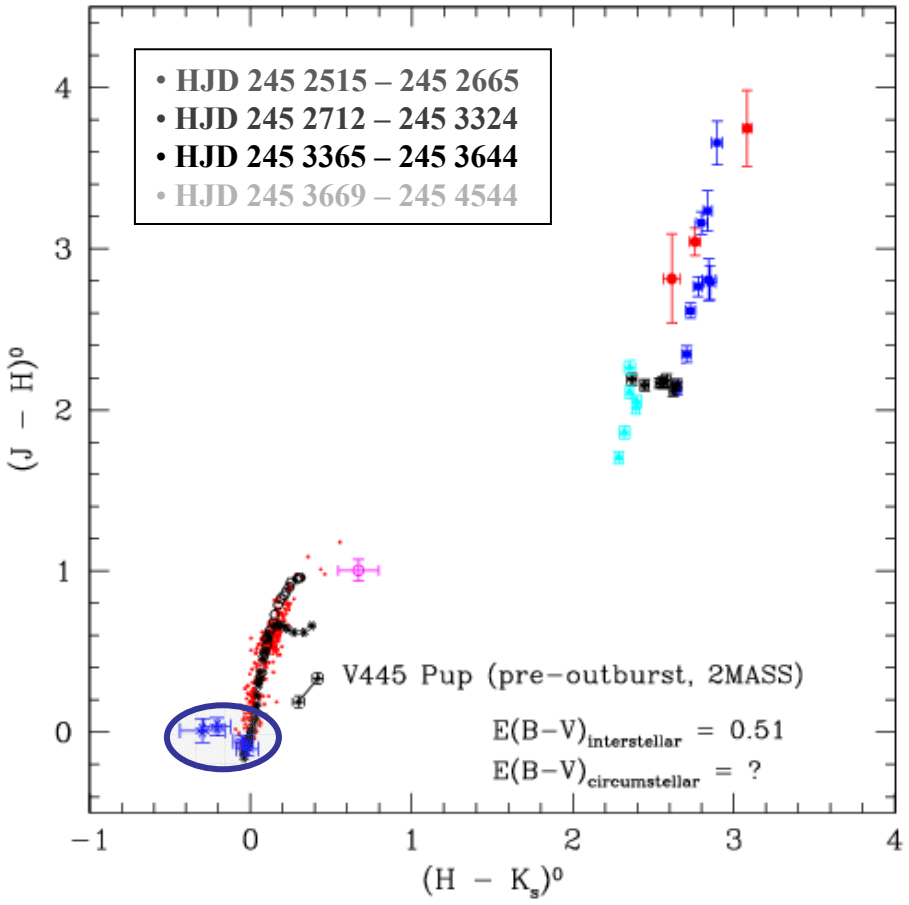
✓ Since 22 March 2002, continuous monitoring



The first observed helium nova
post-outburst observations



Lynch et al (2004)



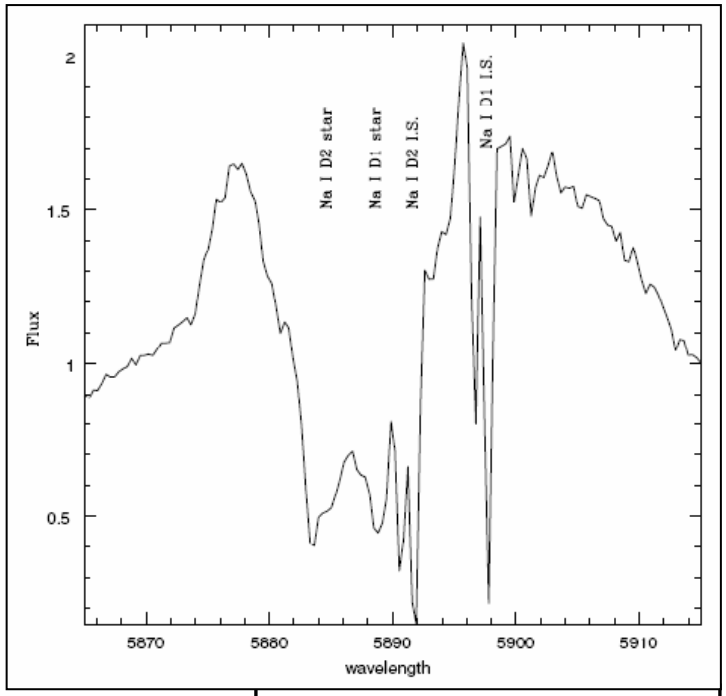
Rapid change in $(J - H)^0$ colour over a 610-day period (blue dots) due to the appearance of He I at 1.0830 micron as seen in the infrared spectra of Lynch et al. (2004).

The first observed helium nova
interstellar reddening

V445 Puppis is located at low Galactic latitude
(l, b) = 241.12°, -2.19°

Schlegel et al. reddening maps: E(B-V) = 0.78
(total line-of-sight reddening; poorly calibrated)

Iijima & Nakanishi (2008): E(B-V) = 0.51 based on interstellar Na D lines



Iijima & Nakanishi (2008)

V445 Puppis **pre-outburst**:

V	14.5 mag	V^0	12.92 mag
J	12.27 mag	J^0	11.82 mag
H	11.94 mag	H^0	11.64 mag
K_s	11.52 mag	K_s^0	11.34 mag

Still too red if underlying binary is AM CVn-like or WD + He star companion…
Circumstellar reddening? Previous outbursts/outflow? Additional E(B-V) ~ 0.8??
Or evolved He star (Kato et al. 2008)?

Expansion parallax:

For an expanding nova shell, the distance to the nova can be determined from high-angular resolution imaging (→ expansion on the sky) and (preferably) integral field unit spectroscopy (→ measure the velocity of the expanding material).

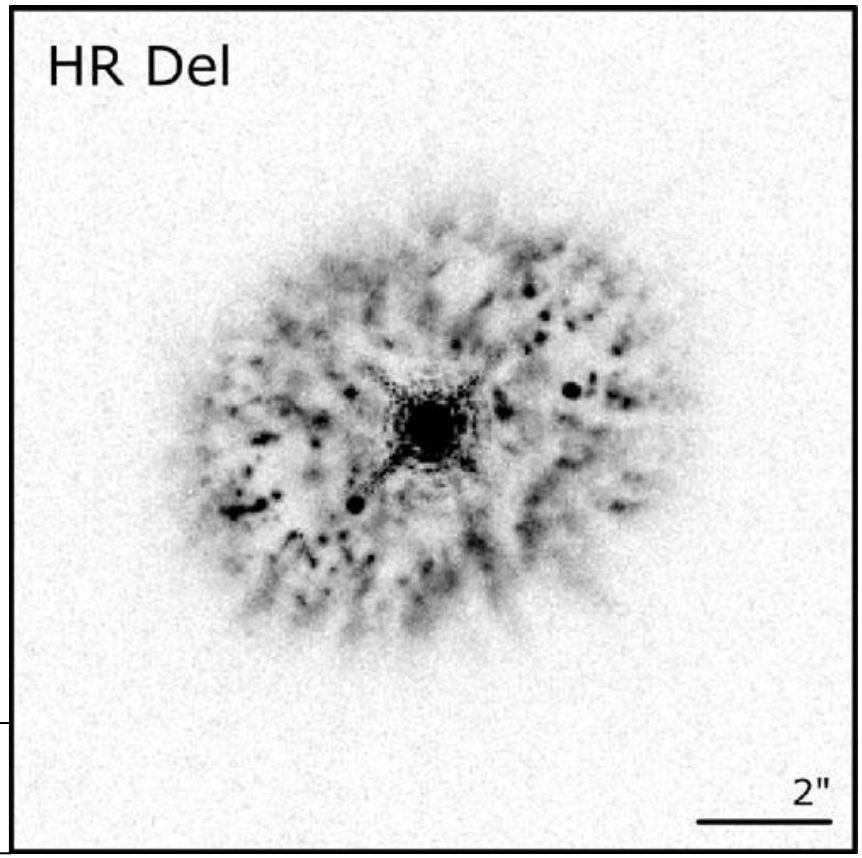
Complications:

- complex (non-spherically symmetric) geometry
- unknown inclination (convert radial into tangential velocities)

Modeling of the shell geometry important.
→ distance error ~10%

$$d = 5.77 \times 10^{-7} \, \Delta t \, v_{\exp} \, \alpha^{-1}$$

d	distance (kpc)
Δt	time since outburst (in days)
v_{exp}	expansion velocity (km/s)
α	angular radius (in arcsec)

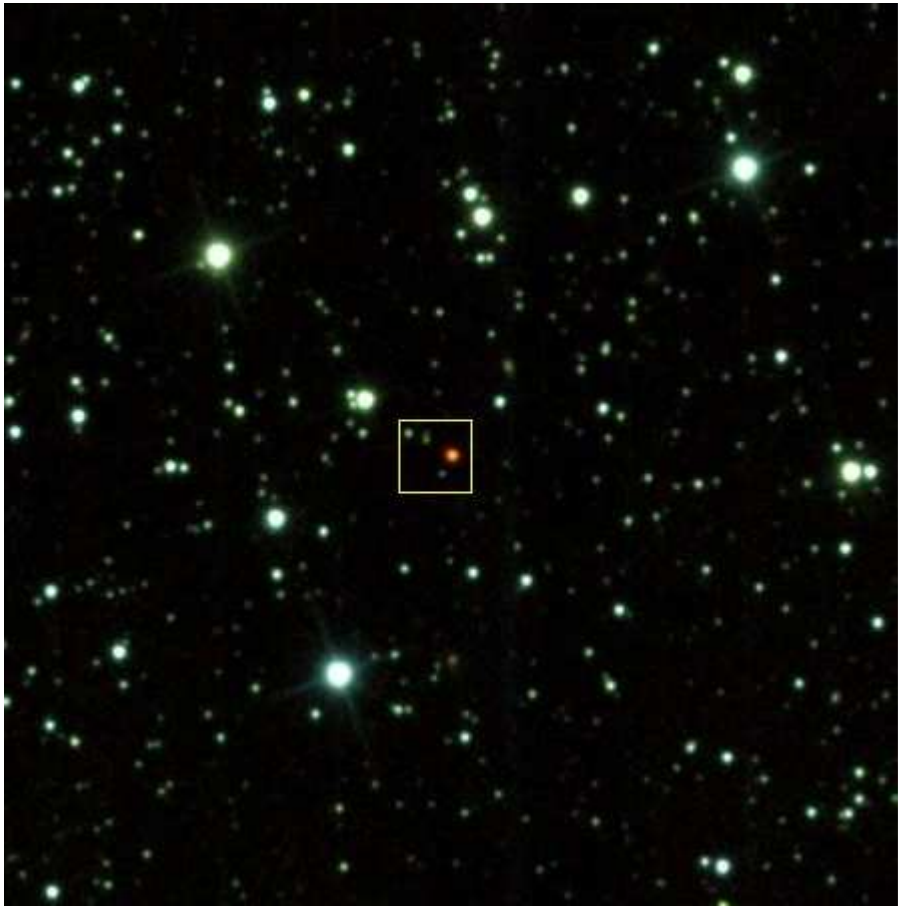


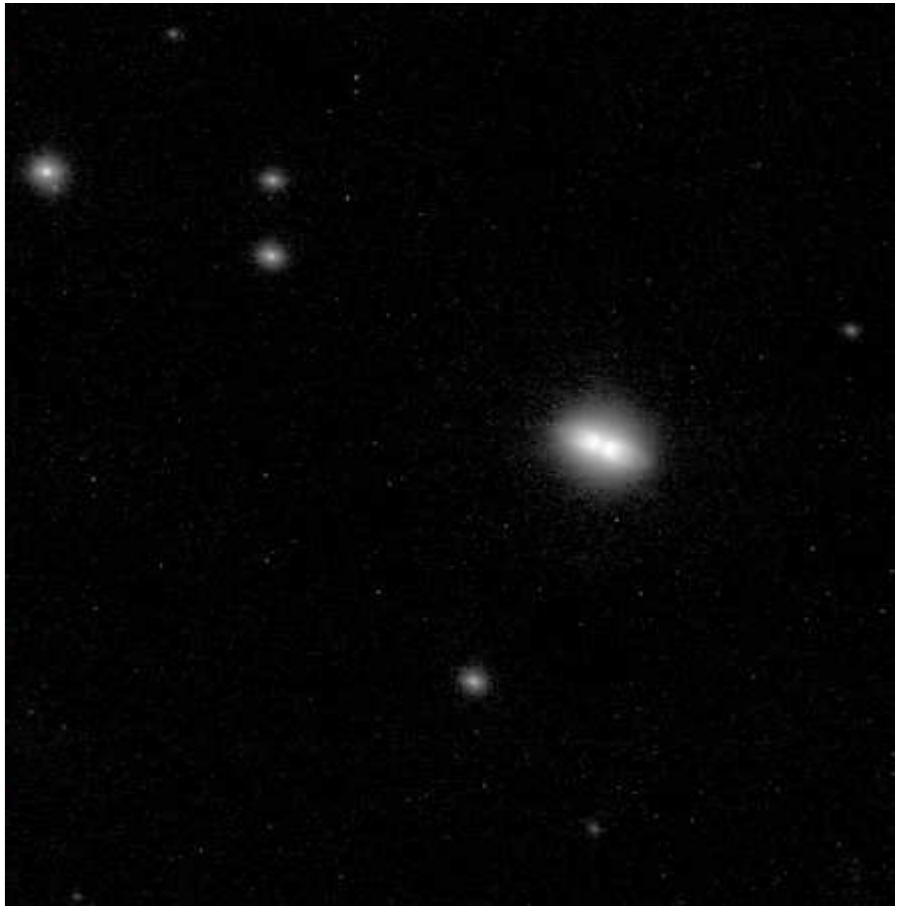
The bipolar shell of the slow nova HR Del (Harman & O'Brien 2003)

The distance to V445 Puppis
Adaptive Optics (AO) near-infrared imaging

Adaptive optics imaging in Ks band with VLT (NAOS/CONICA)

- ✓ Good seeing (0.6 arcsec), FWHM after AO ~ 0.11 arcsec



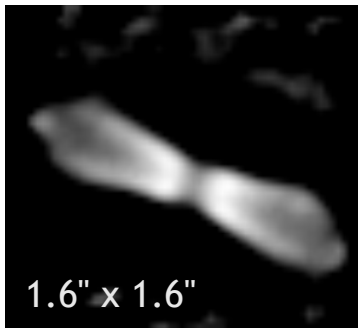


The distance to V445 Puppis
Adaptive Optics near-infrared imaging

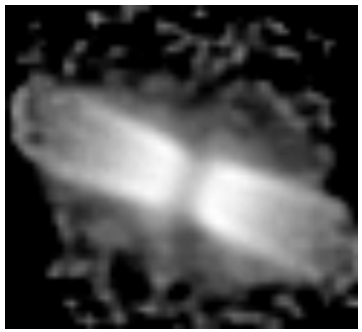
Adaptive optics imaging in Ks band with VLT/CONICA

- ✓ 4 Epochs: March 2005, December 2005, October 2006, March 2007
- ✓ Expanding, bipolar shell

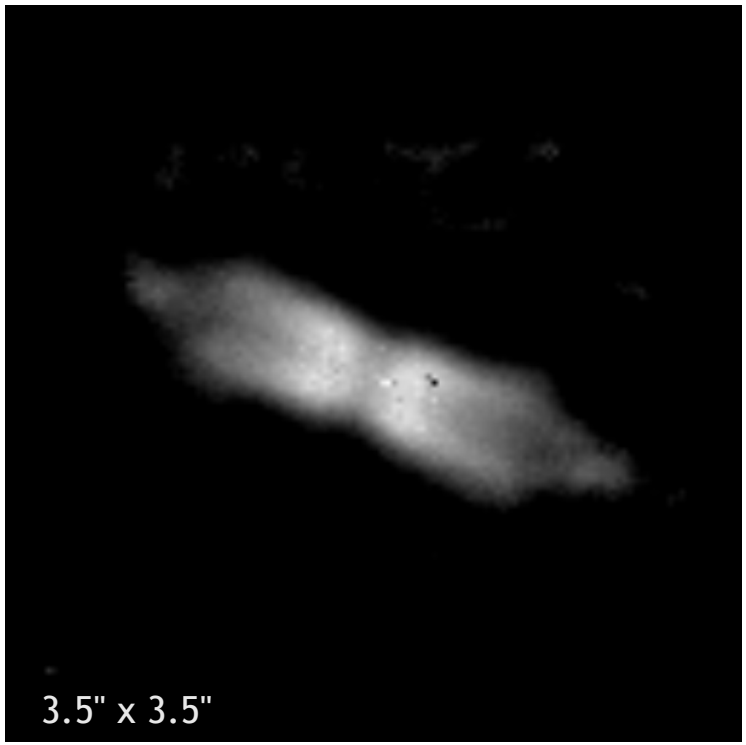
March 2005 (**E1**)



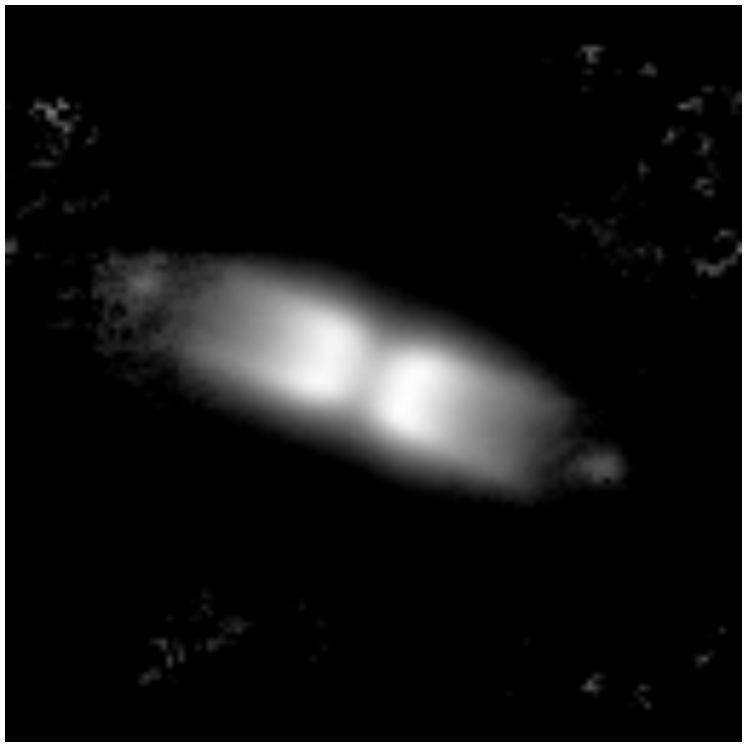
December 2005 (**E2**)



October 2006 (**E3**)

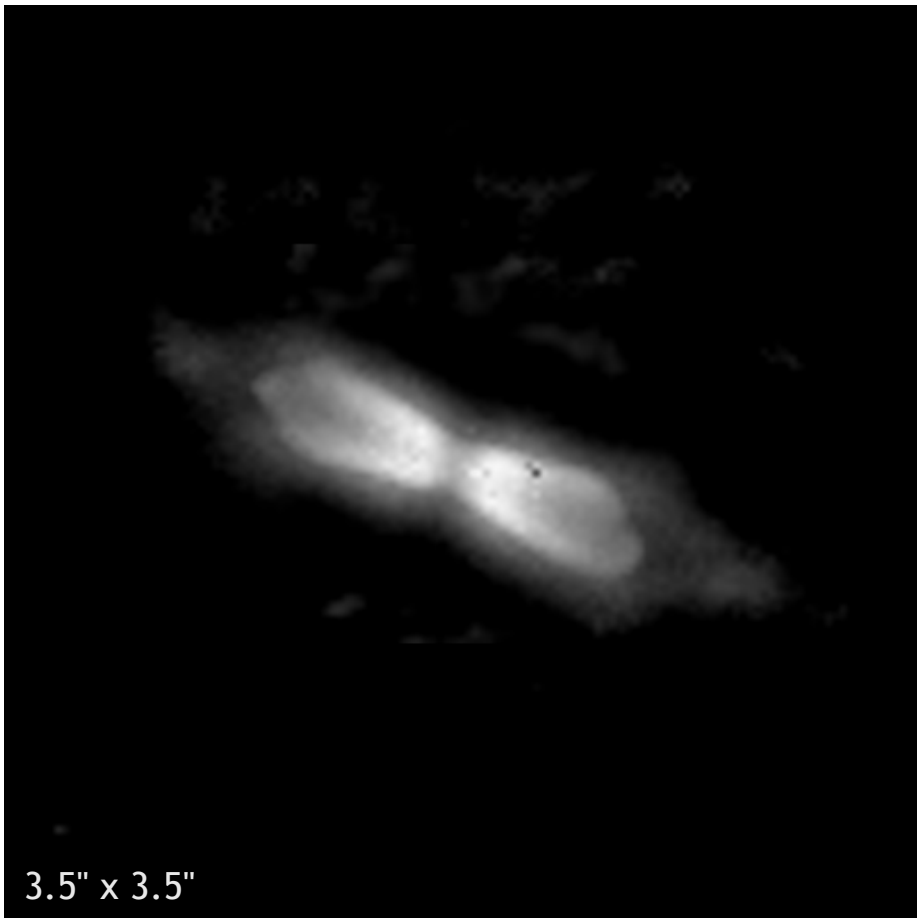


March 2007 (**E4**)

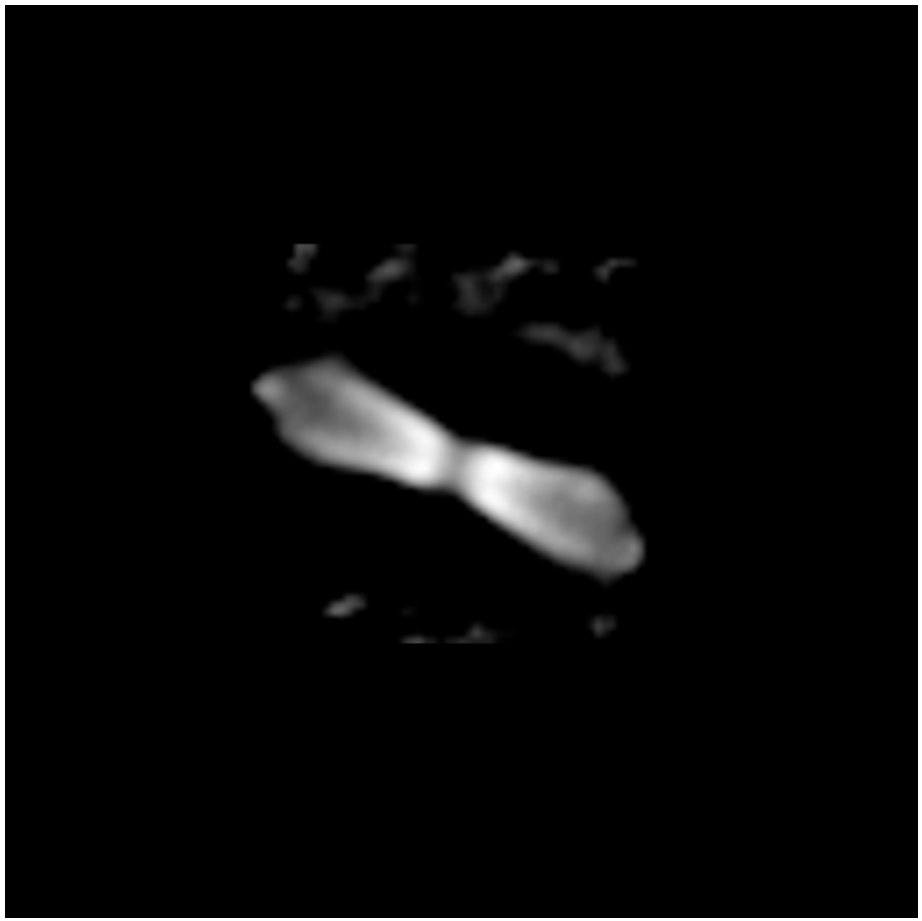


The distance to V445 Puppis
the expanding nova shell

March 2005 (**E1**) + October 2006 (**E3**)



March 2005 - March 2007 (**E1, E2, E3, E4, E1 ..**)



The distance to V445 Puppis
the expanding nova shell

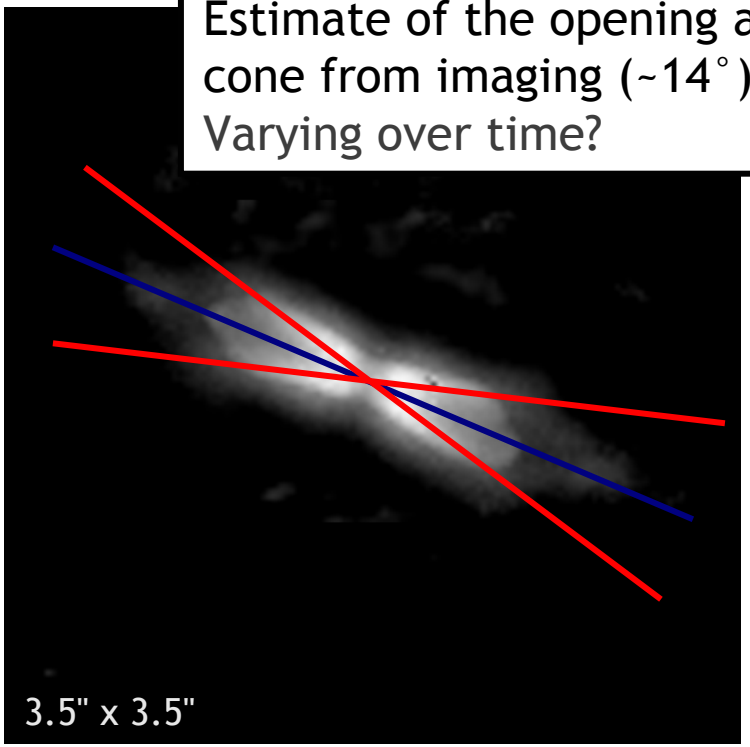
Angular expansion rate:

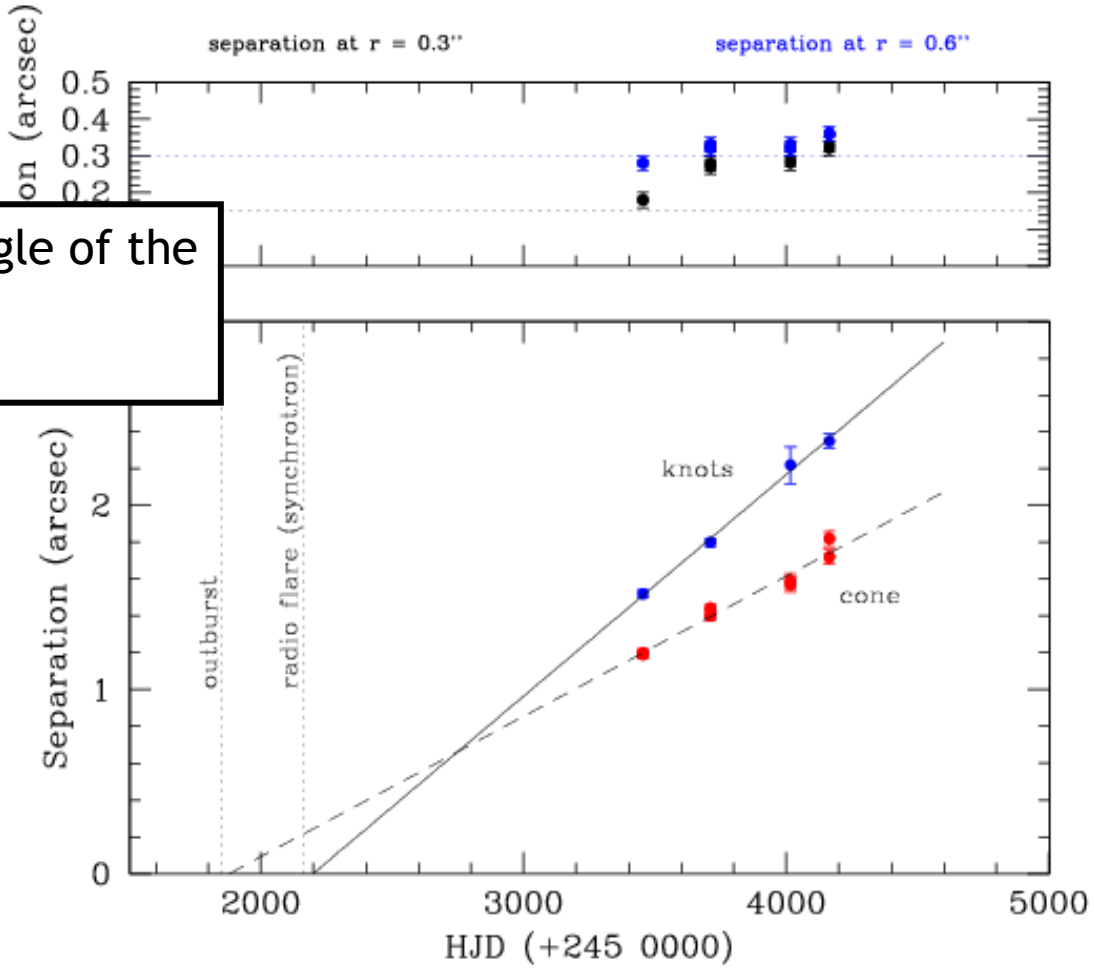
knots 0.220" per year

cone 0.139" per year

knots accelerating?

Estimate of the opening angle of the cone from imaging (~14°).
Varying over time?





The distance to V445 Puppis
near-simultaneous spectroscopy

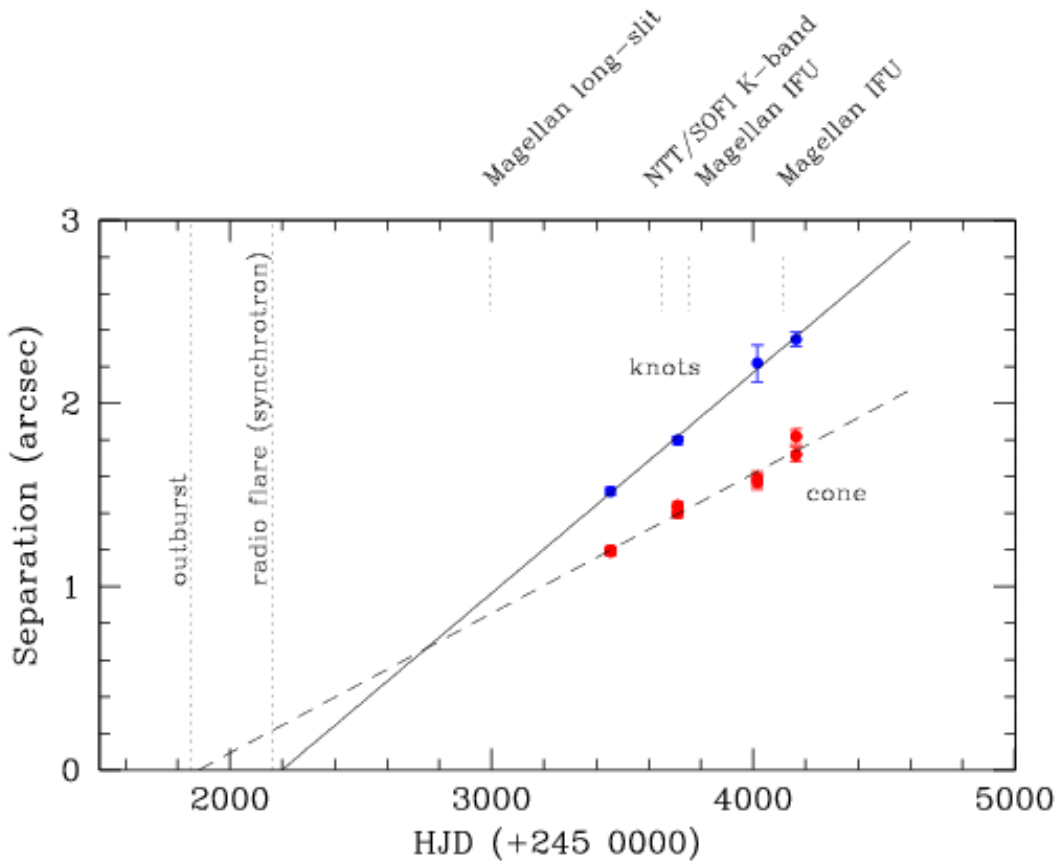
Post-outburst spectroscopy:

Magellan long-slit (Dec 2003)
spatially resolved
velocity structures

NTT/SOFI K-band (Oct 2005)

Magellan IFU (Jan 2006)
spatially resolved
velocity structures,
resolving the two cones
(seeing-limited)

Magellan IFU (Jan 2007)
continued monitoring



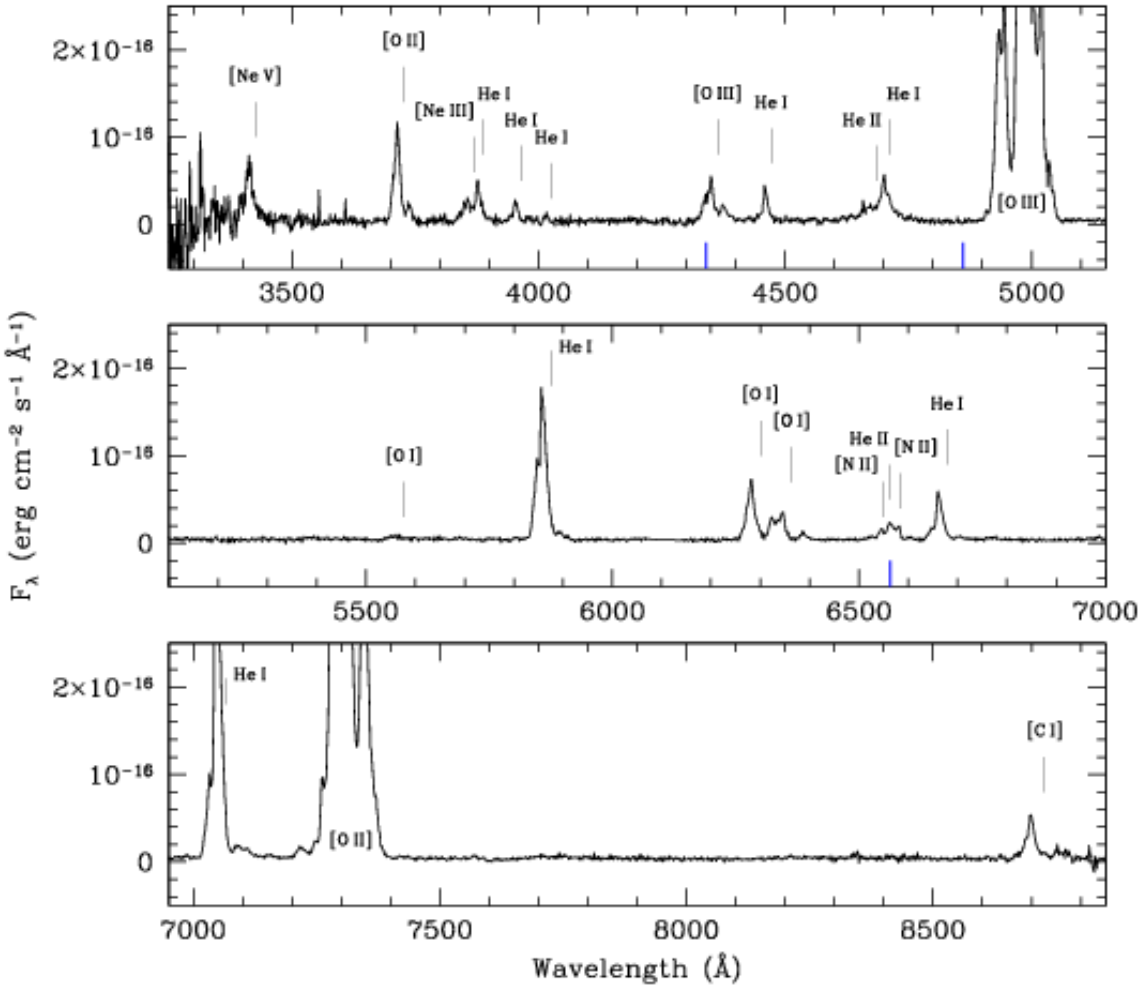
Post-outburst spectroscopy
Magellan (December 2003)

Dominant lines:
- [O II] 7320, 7330 Å
- [O III] 4959, 5007 Å
- He I recombination lines

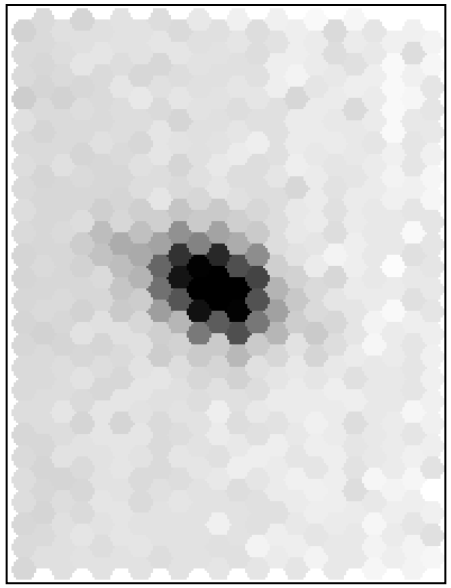
No hydrogen lines!

Multiple velocity components:
-1600, -900, +800 km/s

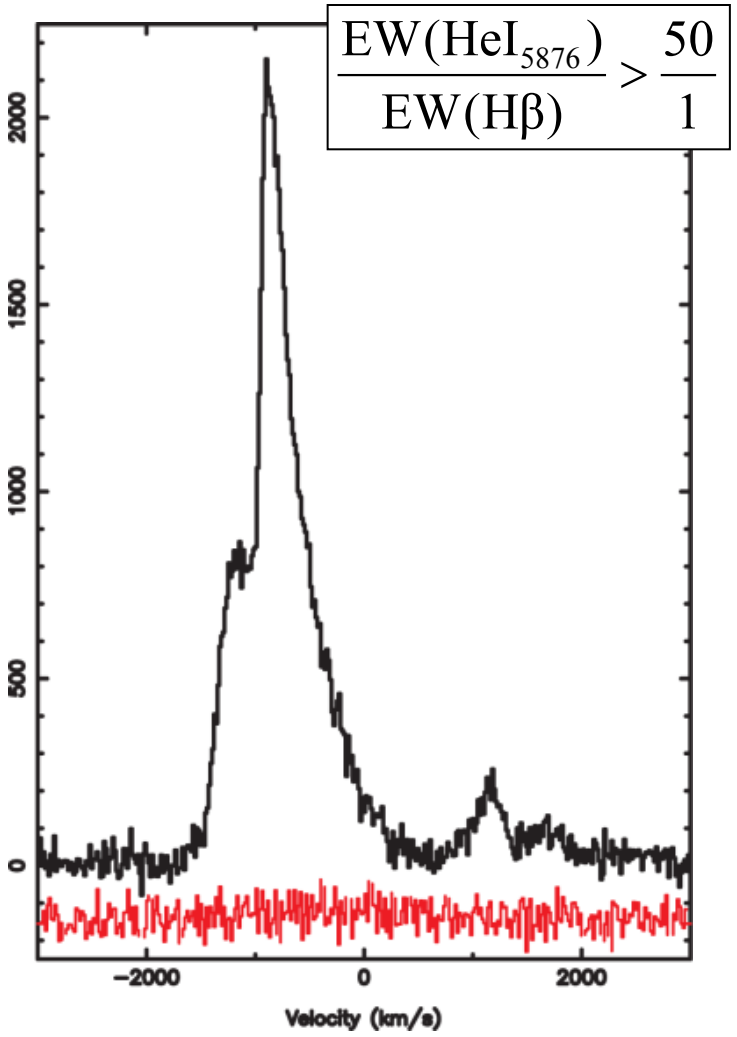
Presence of [O III] 4363 Å and [O II] 7320/7330 Å indicates a high temperature (T_e = 15000 – 20000 K)



Post-outburst spectroscopy
the absence of hydrogen (II)



IFU spectrum obtained with Magellan/IMACS (January 06)



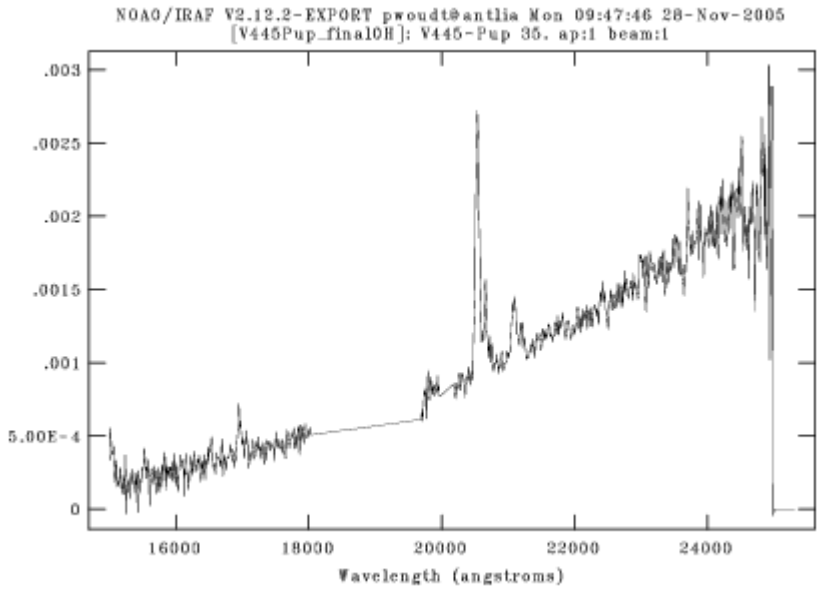
IFU line profile across the central column

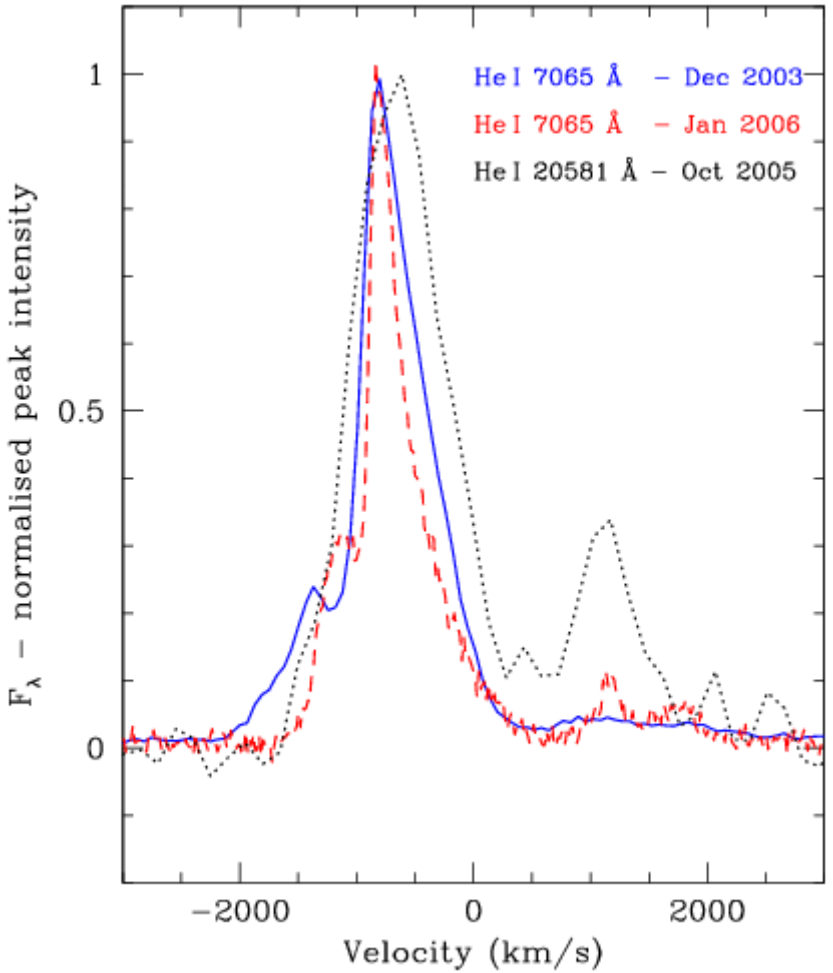
- black: centred on He I at 7065 Å
- red: centred on Hα at 6563 Å

No evidence for any hydrogen.

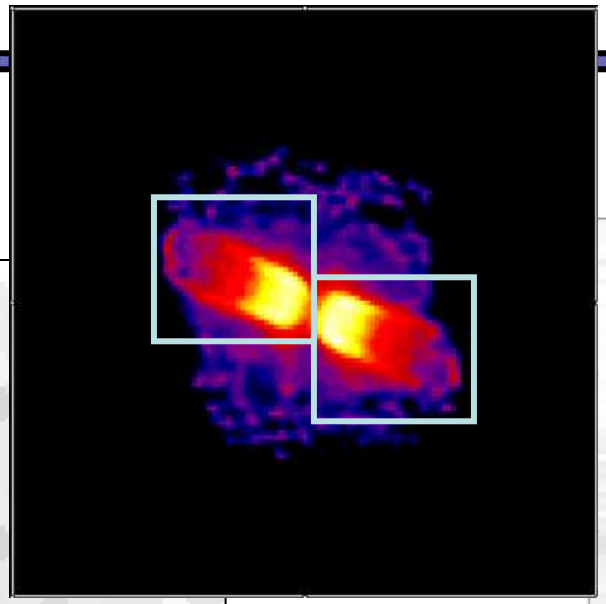
Post-outburst spectroscopy long-slit (2003-2006)

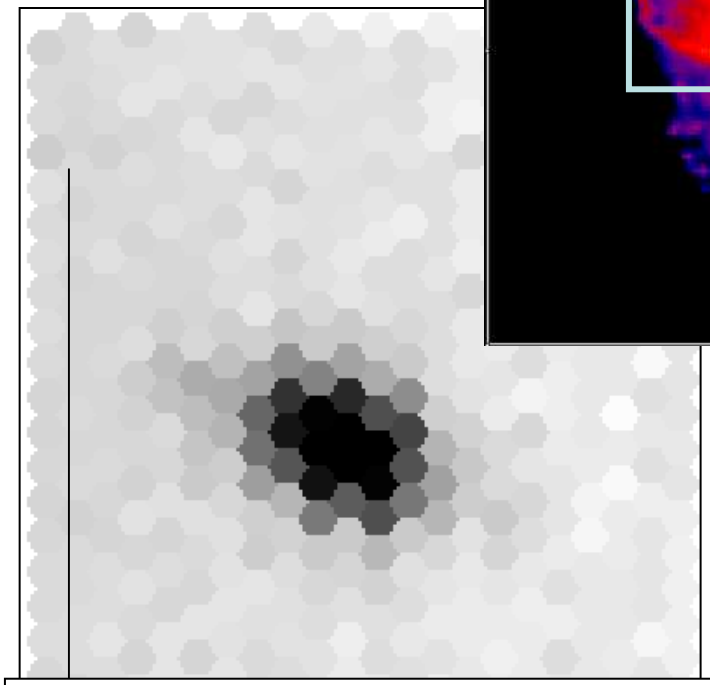
- Velocity profile relatively unchanged over 2-year period.
- Redshifted component heavily obscured by dust in the shell (most prominent at NIR wavelengths)



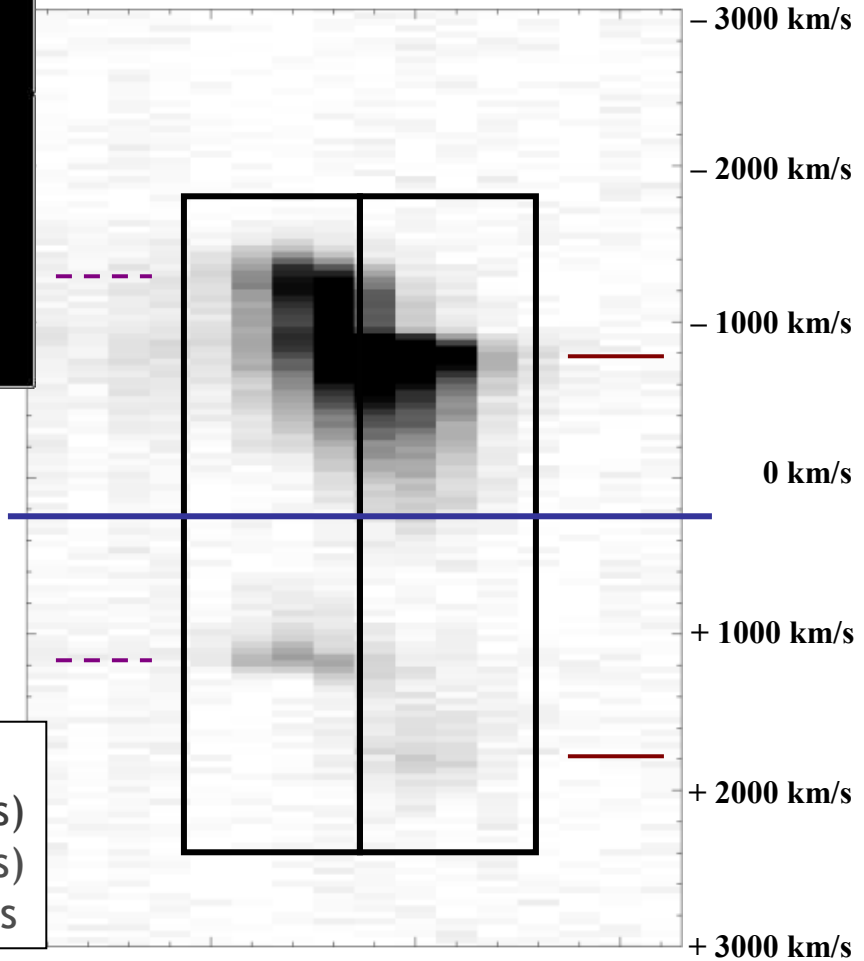


Post-outburst spectroscopy
integral field unit with Magellan/IMACS





He I (7065 Å)



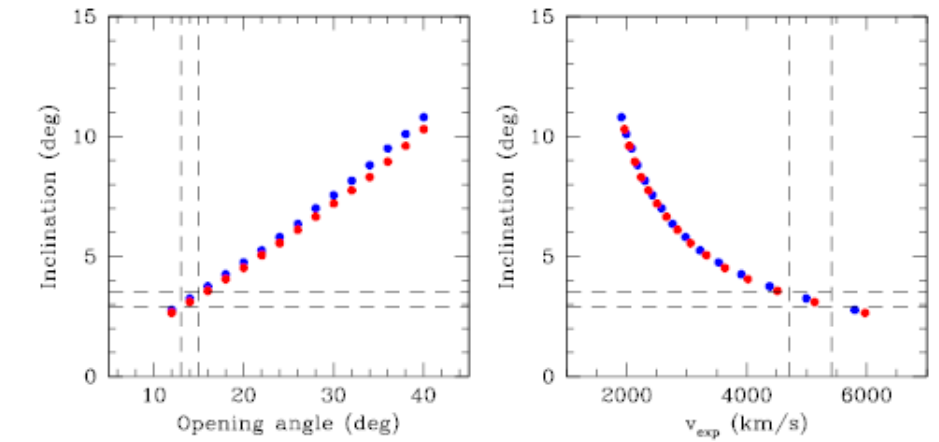
Clear (radial) velocity structure in each line:

NE lobe: -1270 km/s and +1140 km/s (-65 km/s)

SW lobe: -760 km/s and +1720 km/s (+480 km/s)

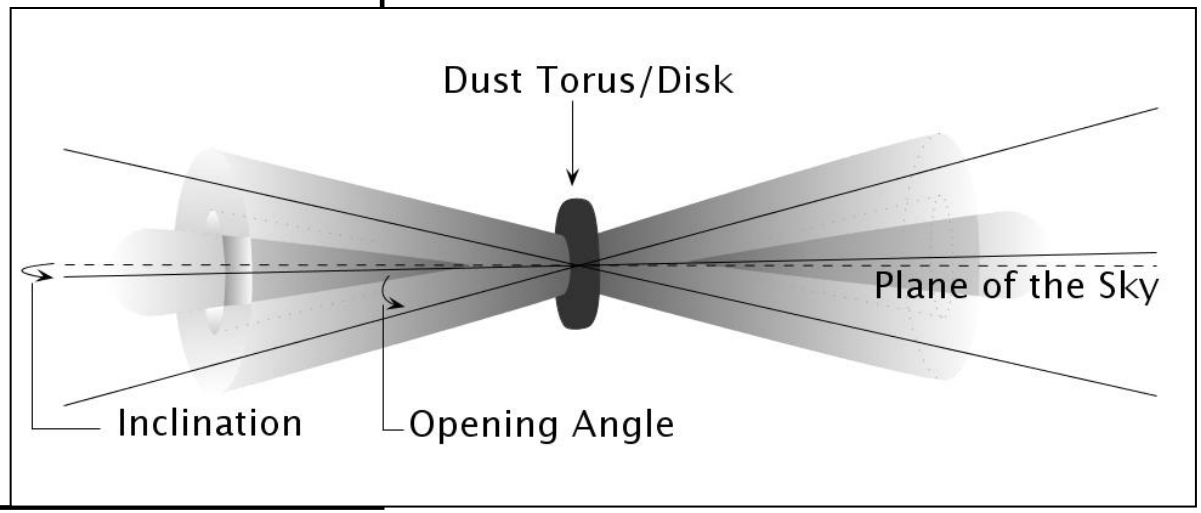
v_{system} = 215 km/s

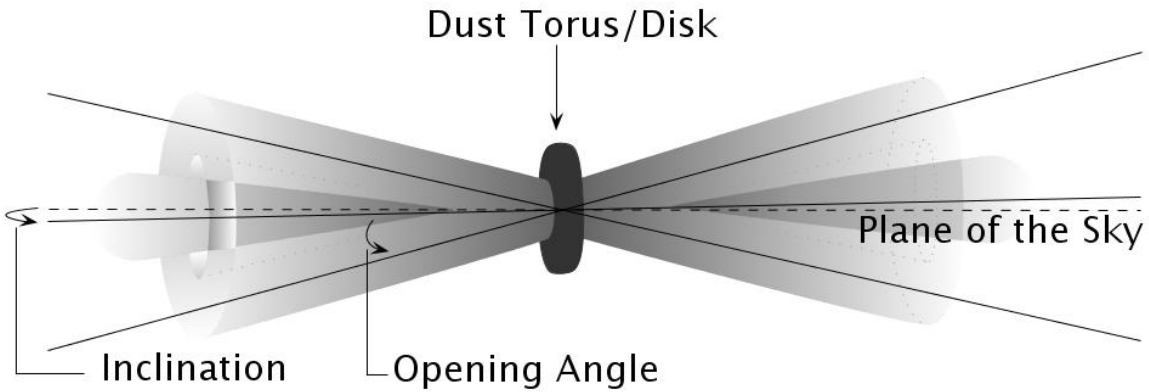
The distance to V445 Puppis
expansion parallax



System parameters:

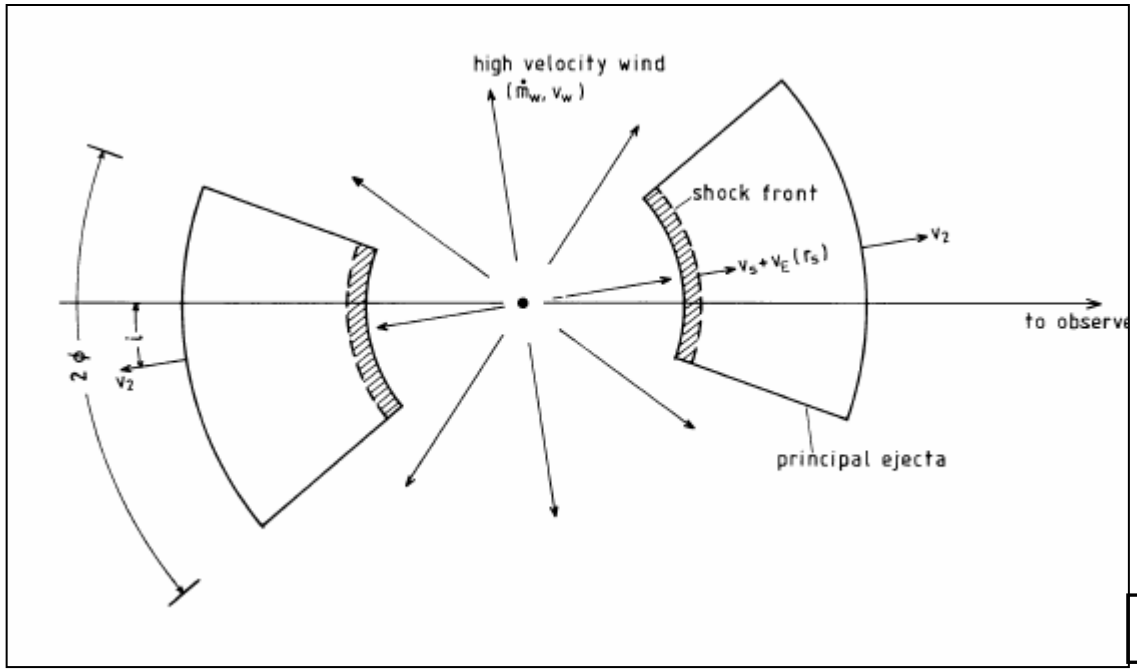
Opening angle:	14° ± 1°
Inclination:	3.2° ± 0.3°
$v_{expansion}$:	5060 ± 500 km/s





Outflow during nova outburst: v = 500 km/s (Iijima & Nakanishi 2008)

Principal ejecta (C-rich); expands, cools, optically thick dust torus forms which still obscured the underlying binary



Outflow in current phase:

Biconical outflow of high velocity wind.

v = 5060 km/s along narrow cone (opening angle 14º)

Emission lines observed through dusty shell.

QU Vul: Taylor et al (1987)

The distance to V445 Puppis
expansion parallax

$$d = 5.77 \times 10^{-7}\, \Delta t\, v_{\exp}\, \alpha^{-1} \qquad \frac{d\alpha}{dt} = 0.381\,\text{mas/day} \qquad v_{\exp} = 5060\,\text{km/s}$$

$$d = 7.7 \pm 0.8\,\text{kpc}$$

Note:	Angular expansion from Ks band imaging (dusty shell), expansion velocity from emission lines seen through the dusty shell.
	Is the expansion of the dusty shell physically associated with the excited gas ([OII], [OIII], HeI) traced by emission line spectra?
Yes?	Emission line structures are clearly from a biconical outflow; Shell appears obviously bipolar.

V445 Puppis: the underlying binary
absolute magnitude/reddening correction

$$m_V - M_V = 5\log d - 5 + A_V$$

$$14.5 - M_V = 14.4 + A_V$$

$$M_V \approx -A_V$$

Note: Pre-existing circumstellar extinction?

Galactic foreground extinction: A_V = 1.58 mag (interstellar NaI D lines)

Circumstellar extinction: A^i_V ~ 2.5 mag (to make pre-outburst colours consistent with high Mdot AM CVns)

$$M_V \approx -1.5 \text{ to } -4$$

Note: bolometric correction… (AM CVns: BC ~ -2.5 Roelofs et al. 07)

V445 Puppis (pre-outburst): $2.5 \leq \log\left(L/L_{\text{Sun}}\right) \leq 4.5$

The helium nova V445 Puppis
conclusions

General properties of the shell/ejecta:

- C-rich ejecta
- biconical outflow
- dusty equatorial torus
- prolonged period of dust obscuration (chance orientation)
- [$M_{ejected}$ = 1x10^{-5} M_{Sun} (Lynch et al. 2004, scaled up with distance)]

Distance:

- 7.7 ± 0.8 kpc from expansion parallax (cool shell vs. emission lines of ionized gas observed through the shell)
- very luminous: 2.5 < log (L/L_{Sun}) < 4.5… what about all those uncertain corrections
- massive WD? accretion luminosity or luminous donor? (wait for dust to clear)

Helium novae (lessons learned from V445 Puppis, sample of 1):

- most extreme bipolar nova shell: typical for He novae? (slow nova)
- longest dust block-out in any nova: typical for He novae?
- no firm constraint on nature of underlying binary