Late-time *Hubble Space Telescope* imaging of the outburst of the recurrent nova RS Ophiuchi

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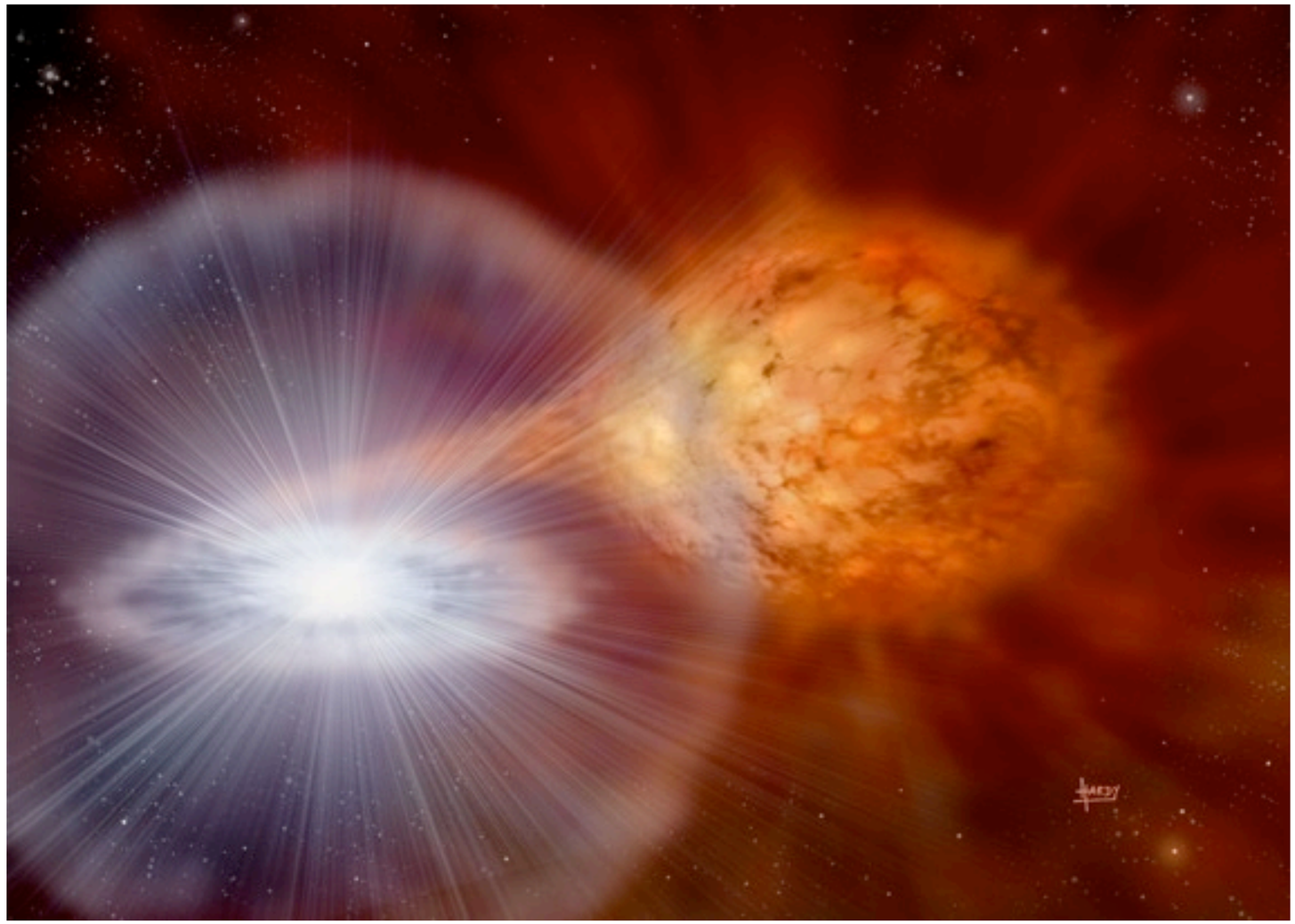
Stella Novae: Future and Past Decades -- 4 - 8 February 2013

Outline

* RS Oph Vital statistics
* Resolved imaging (Radio and Optical)
* Modelling the late time optical imaging
* Summary



D. Hardy/PPARC

RS Oph Vital Statistics

* Recurrent Nova - previous outbursts 1898, (1907), 1933, 1945, 1958, 1967, 1985 and 2006 (Feb 12.94)

* d = 1.6 ± 0.3 kpc (Bode 1987, Barry et al. 2008)

* Central system - high mass WD (1.2-1.4 $M_{\odot}$?) + Red giant (M2 III)

* Outburst due to Thermonuclear Runaway on WD surface

* Multifrequency observations of latest outburst - Swift, XMM, Chandra, RXTE, MERLIN, VLA, VLBA, EVN, LT, UKIRT, GMRT, Ryle, Spitzer, HST

* Very similar optical behaviour to previous outbursts and early X-rays consistent with simple shock models (e.g. Bode et al 2006; Sokoloski et al. 2006)

2006 Outburst

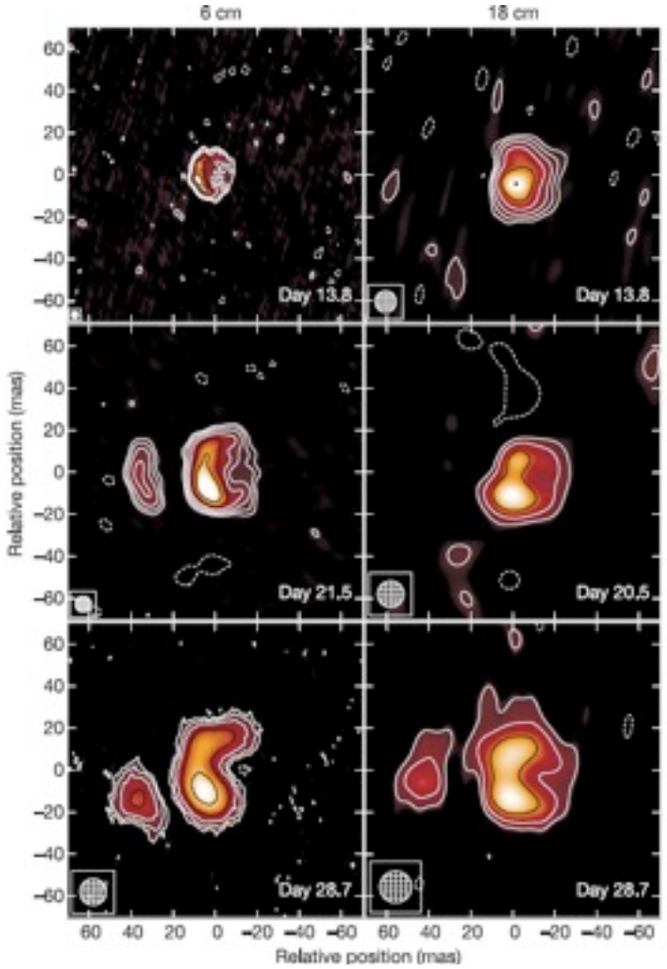
* VLBI observations at t = 13.8 showed a partial ring of non-thermal radio emission (from expanding shock) which at later times develop to a bipolar structure (O'Brien et al. 2006, 2008)

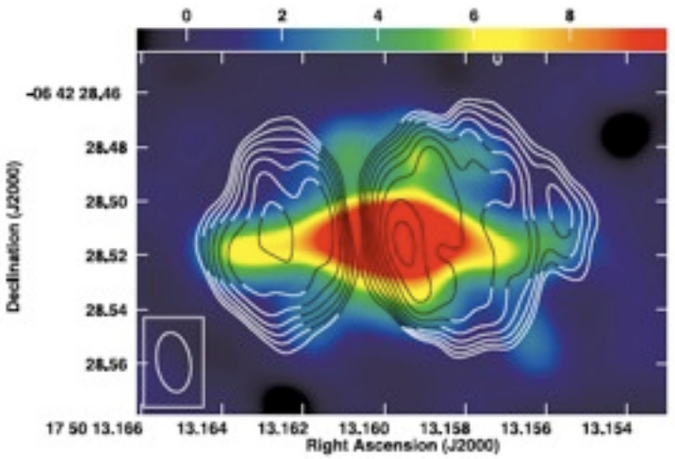
* The asymmetry was suggested to be due to absorption in the overlying red giant wind and more extended components to the east and west also emerged

* VLBA observations between 34 and 51 days after outburst showed what appeared to be highly collimated outflows (Sokoloski et al. 2008)

* Taylor et al. 1989 and Sokoloski et al. 2008, both interpret the system as having a central thermal source with expanding non-thermal lobes

O'Brien et al. 2006





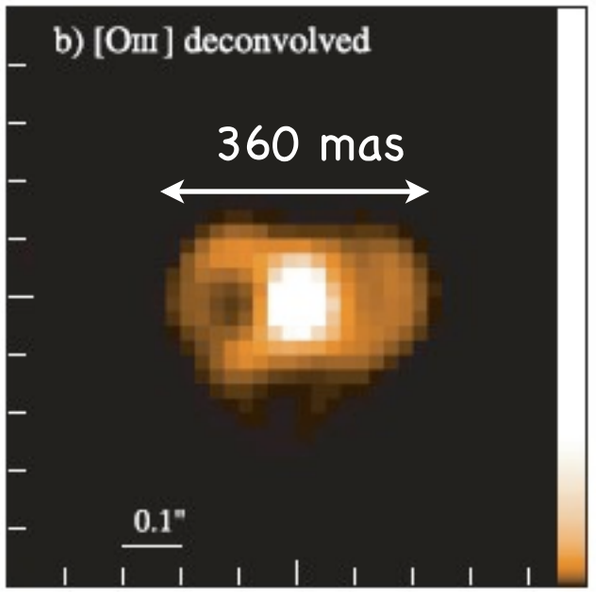
Sokoloski et al. 2008

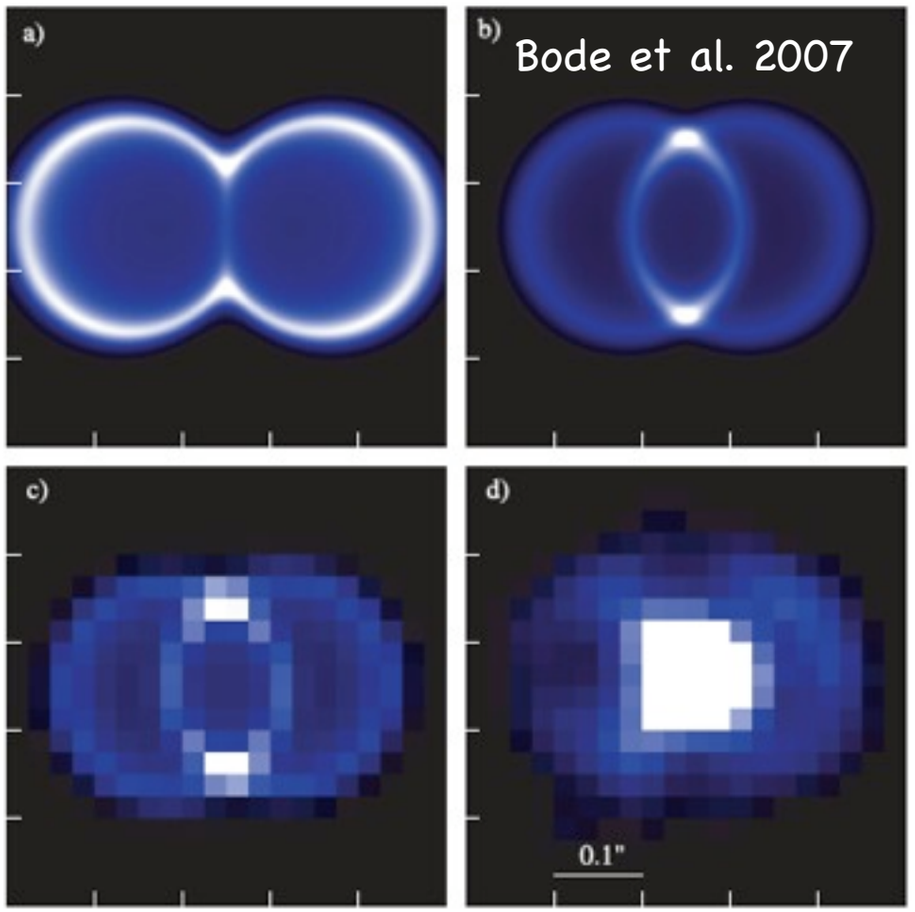
2006 Outburst

* HST optical imaging at 155 days after outburst revealed that the expanding nebular remnant had a double ring structure (Bode et al. 2007)

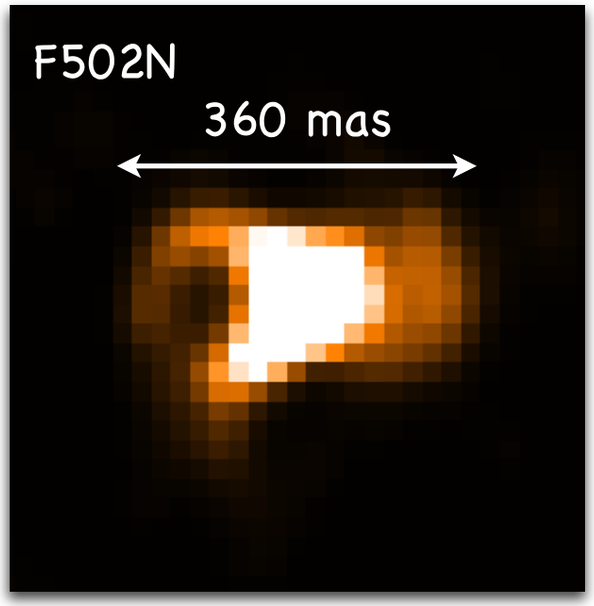
* They suggested there is deceleration in the north-south direction when comparing with earlier observations in the radio

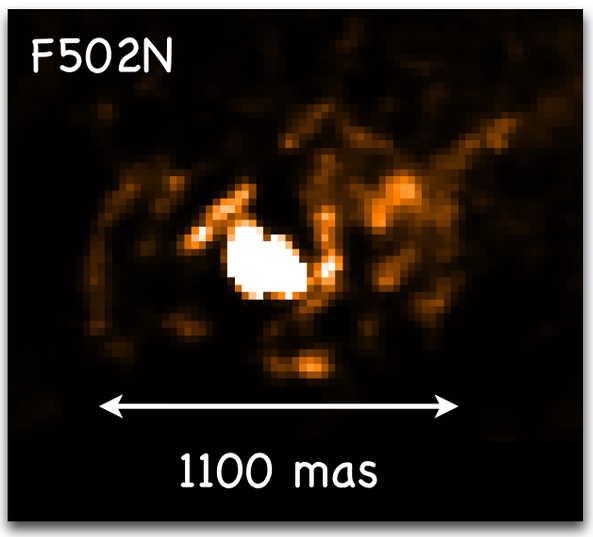
* Bode et al. 2007 also provided preliminary models of the remnant as a bipolar structure which implied a true expansion velocity of 5600 ± 1100 km/s

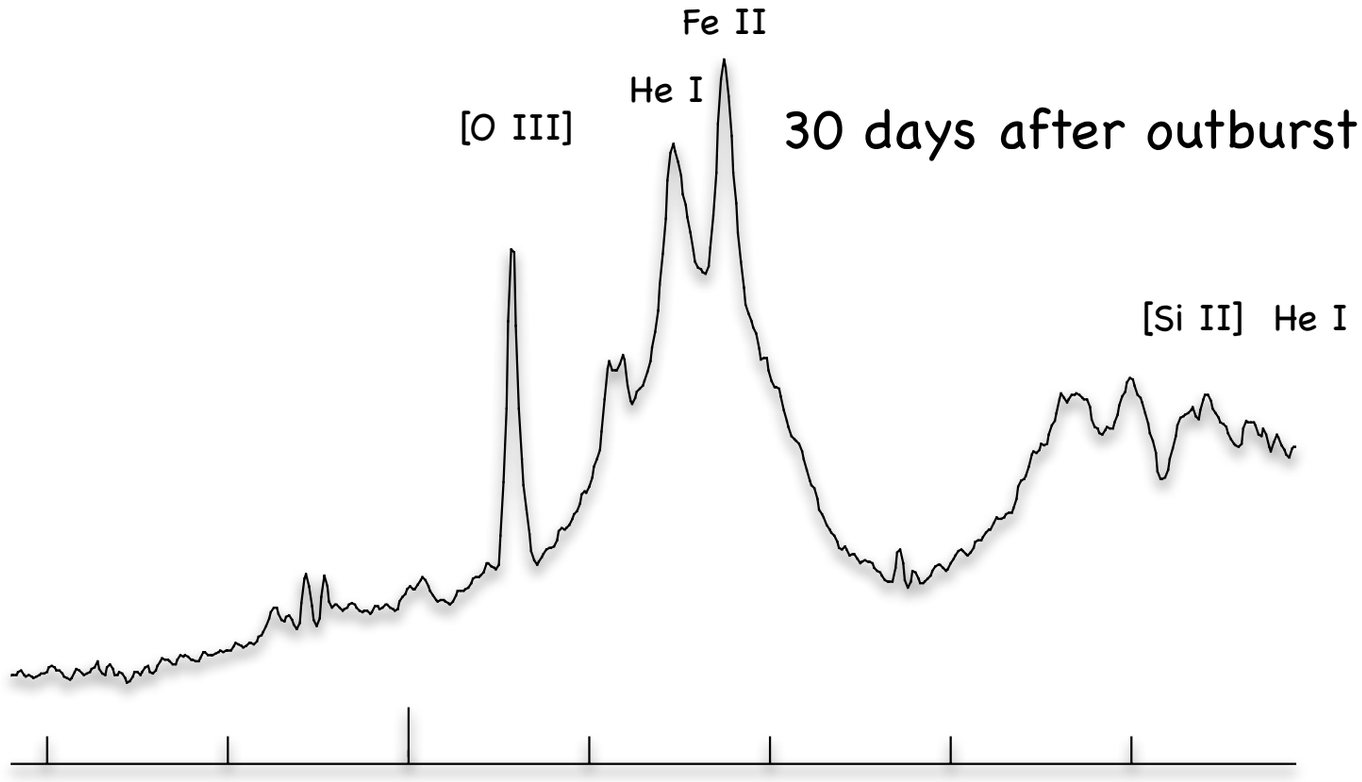


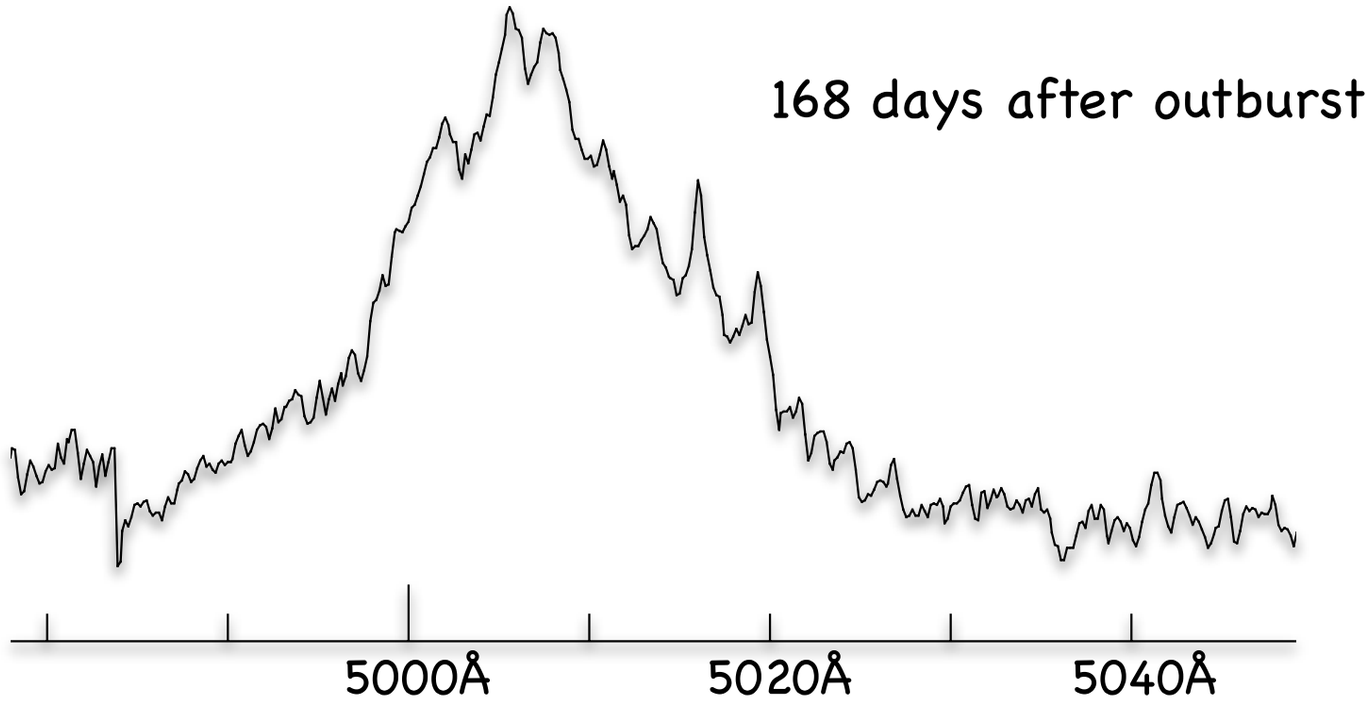


Spectra

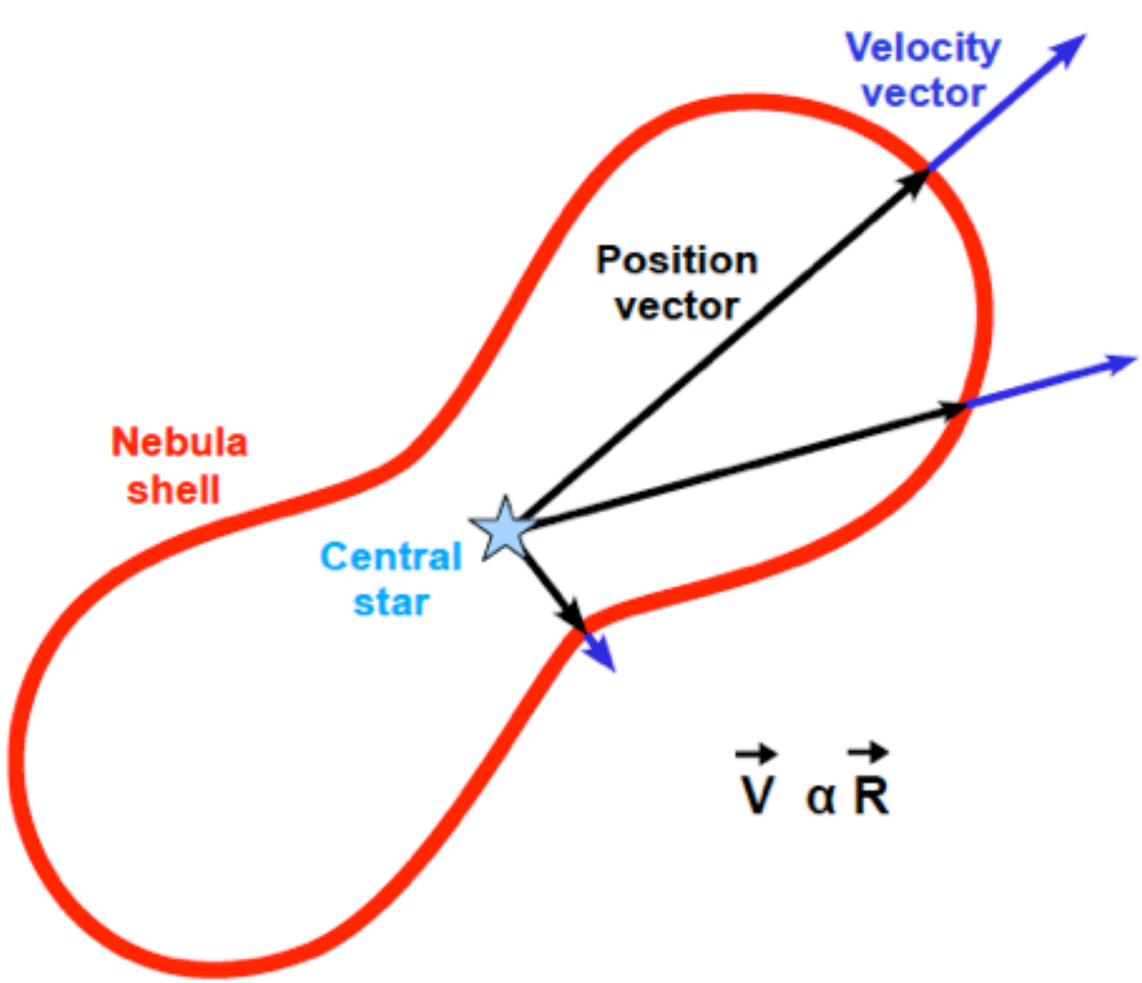

F502N
360 mas

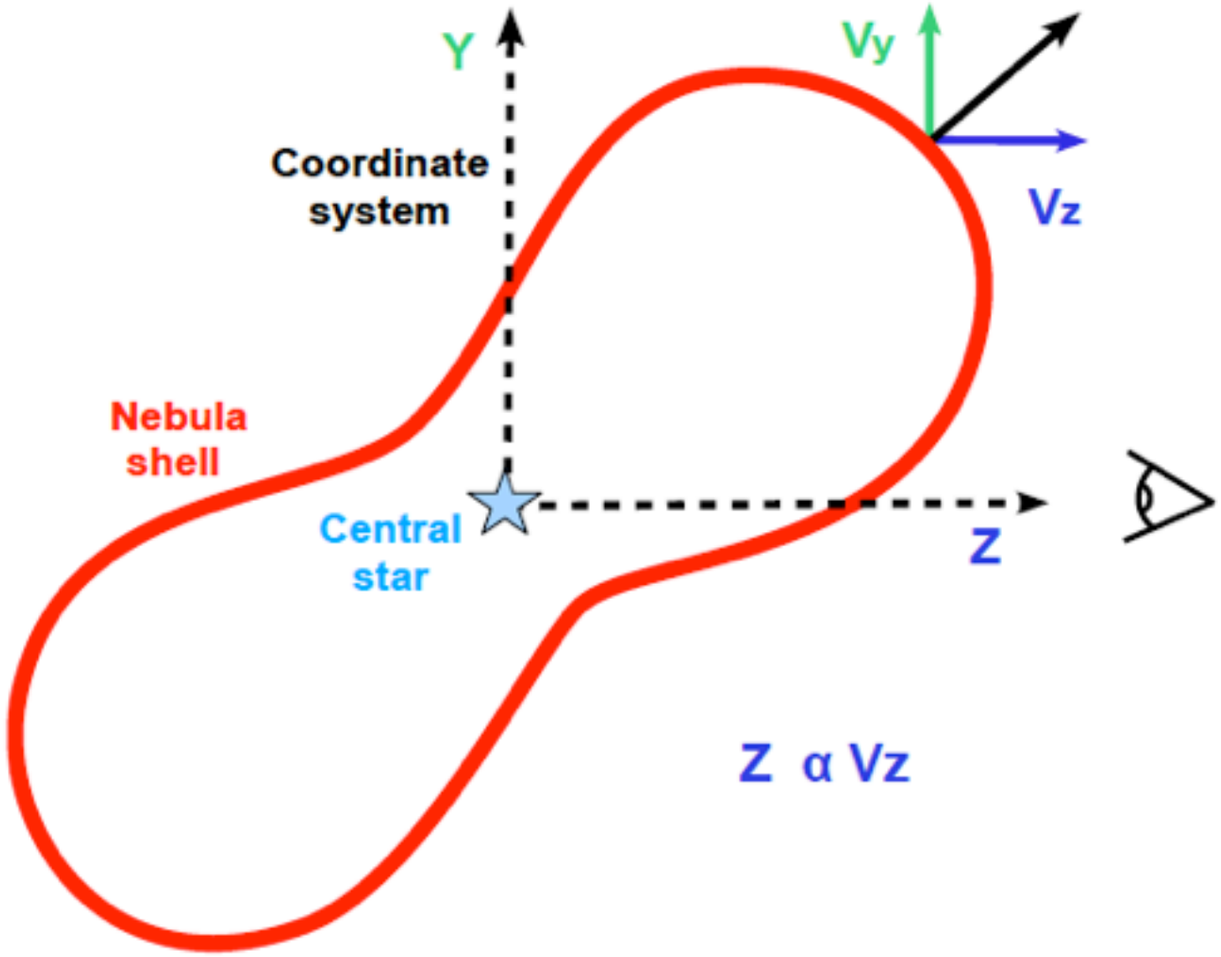

F502N
1100 mas


Fe II
He I
[O III]
30 days after outburst
[Si II]
He I


168 days after outburst
5000Å
5020Å
5040Å

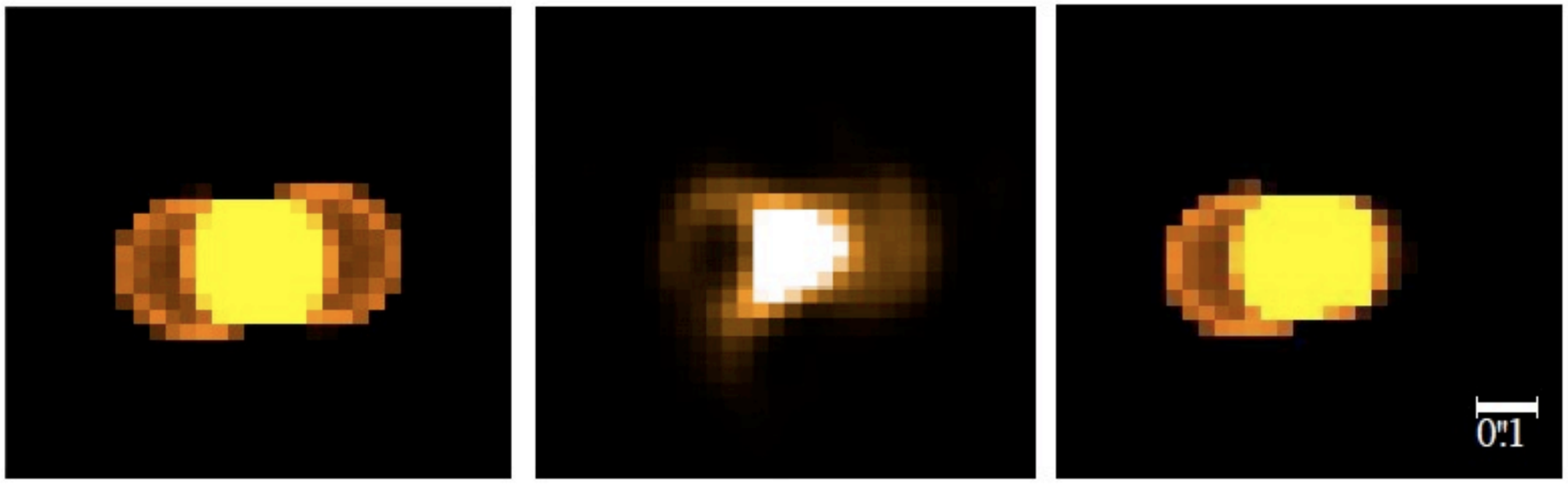
Steffen, et al. 2010

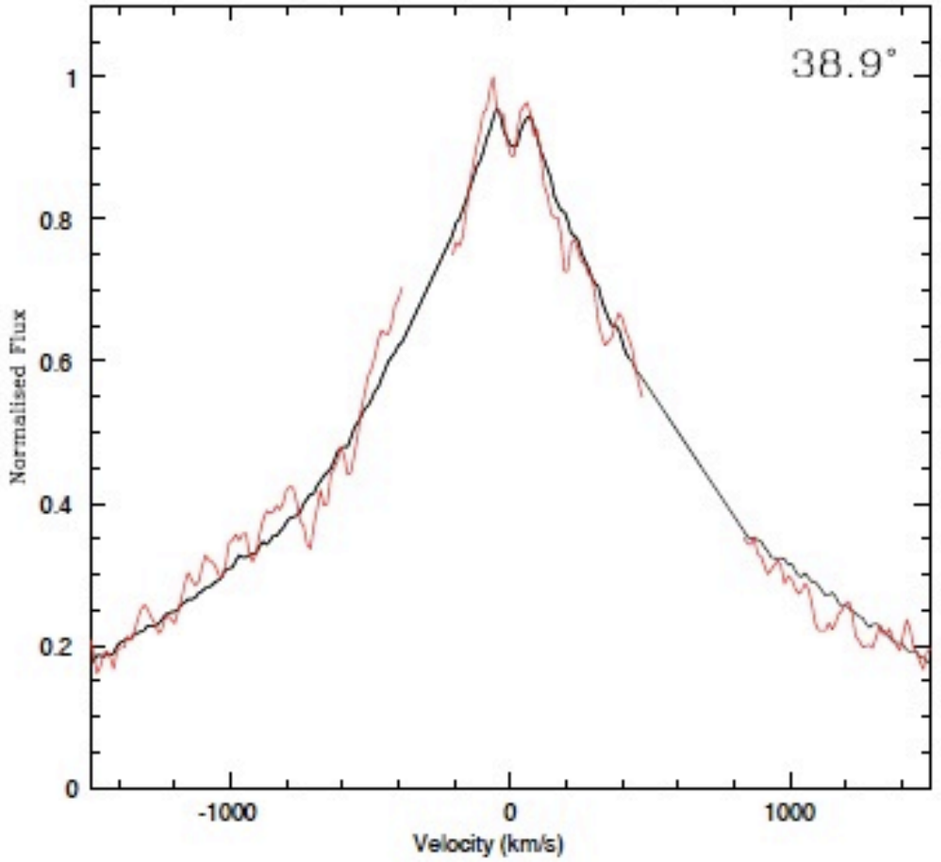


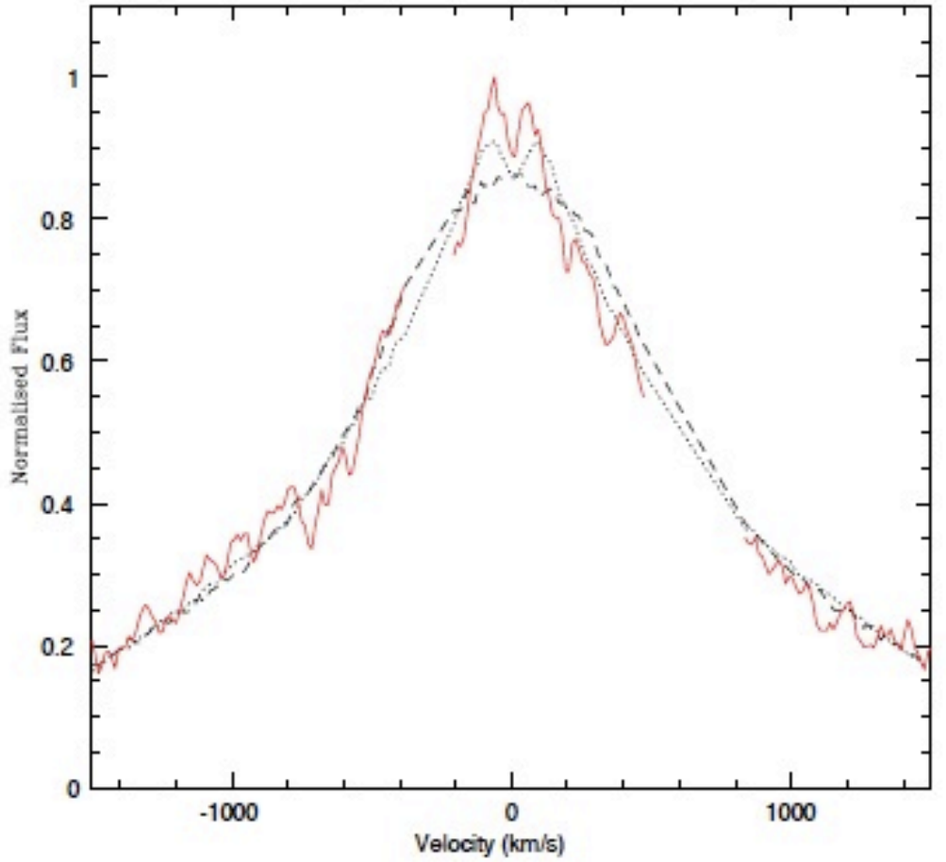


2006 Outburst

Ribeiro, et al. 2009





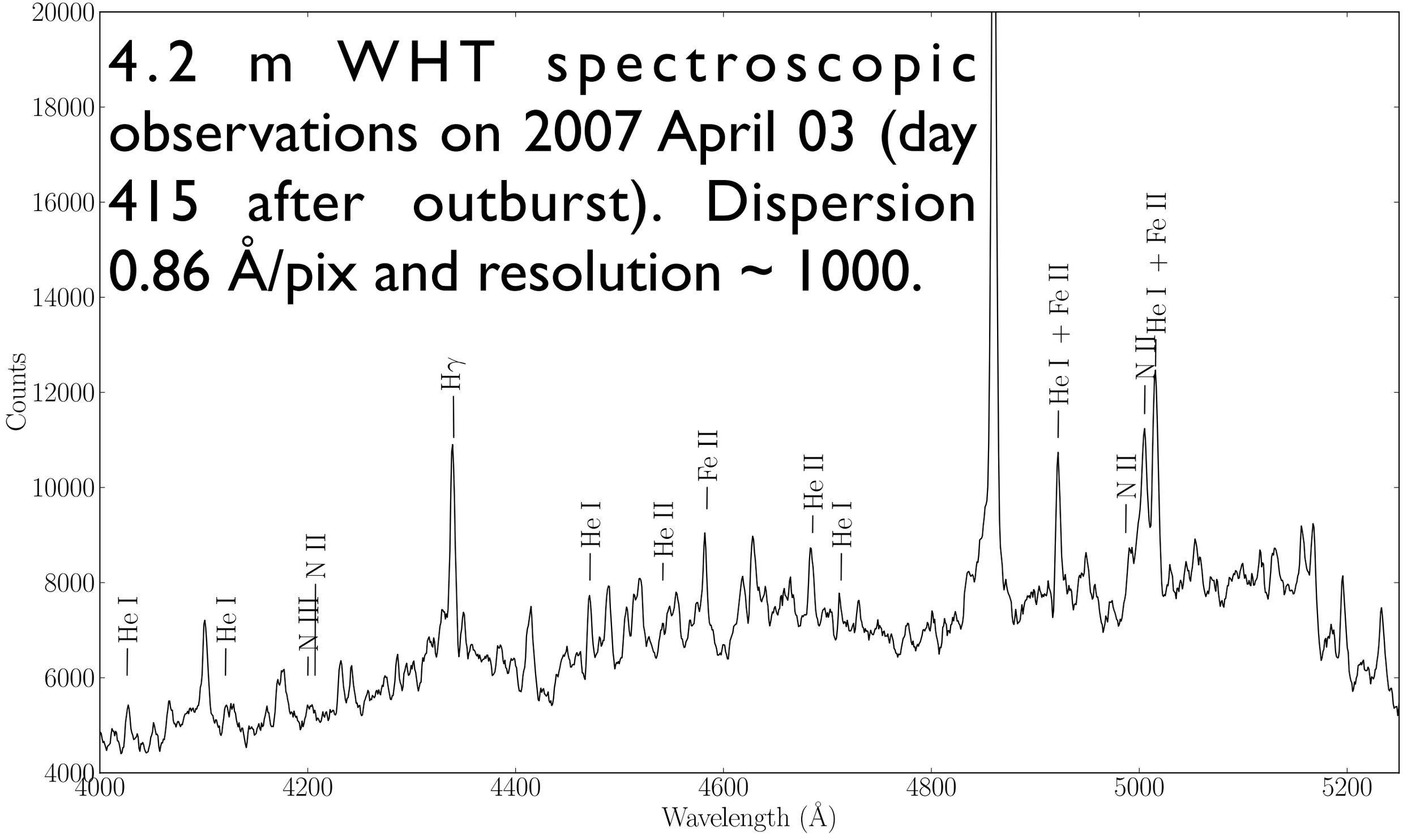


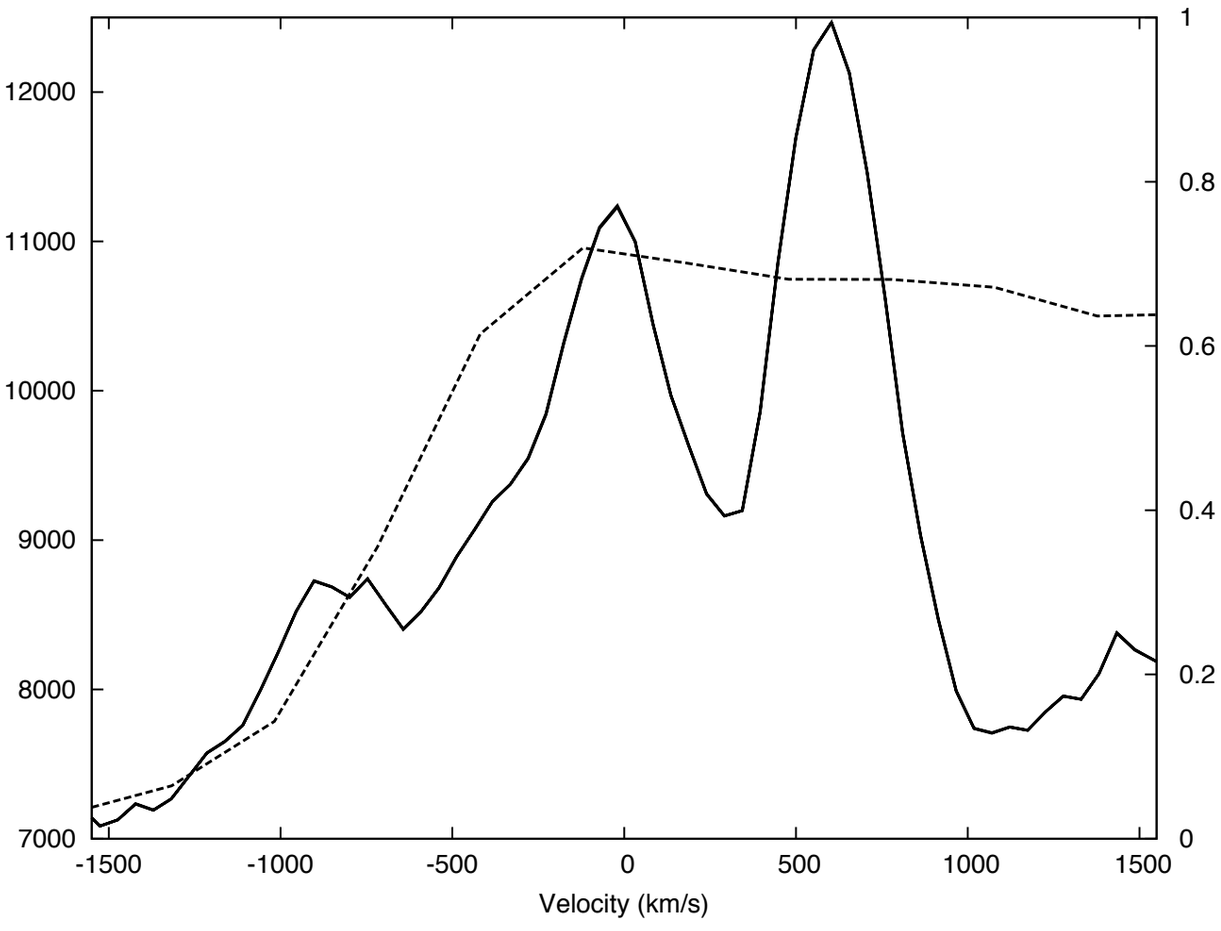
- The second epoch was much harder to model, constrain and thus open to over-interpretation

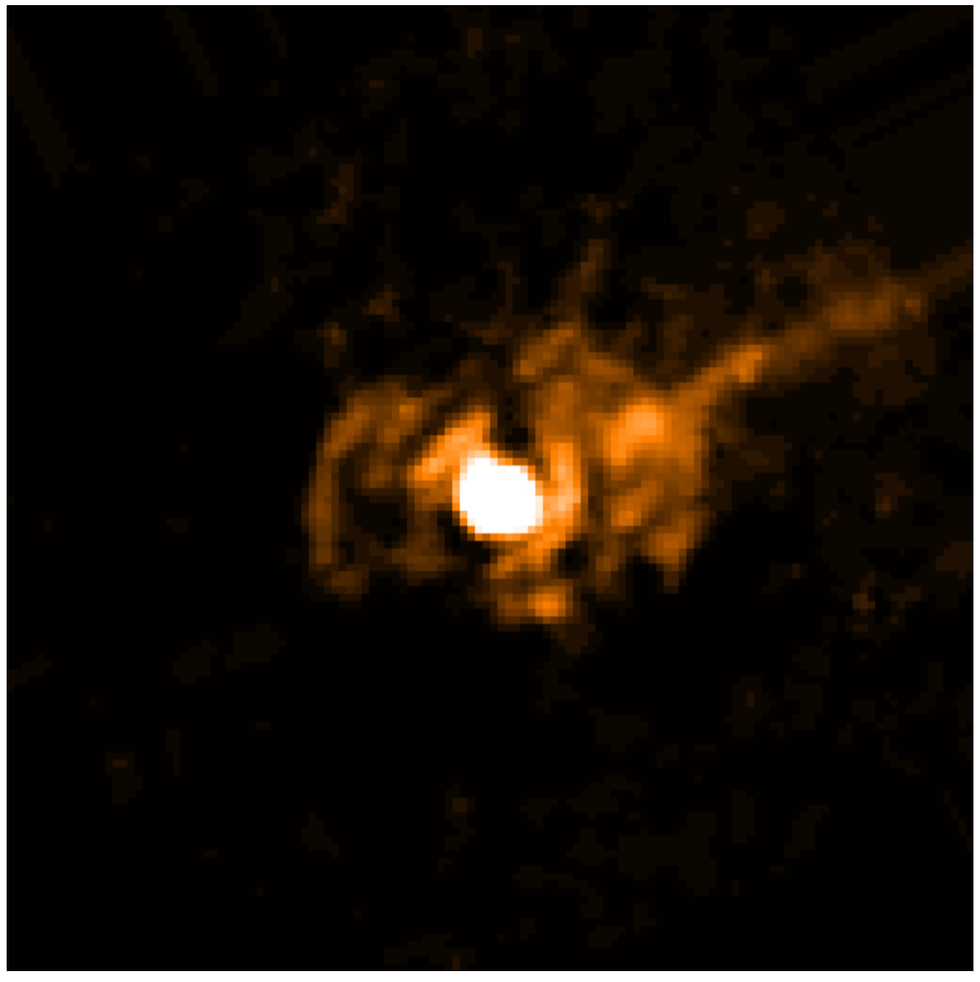
- The model implies that the outer structure underwent a linear expansion; however, there is more evidence of deceleration for the central region

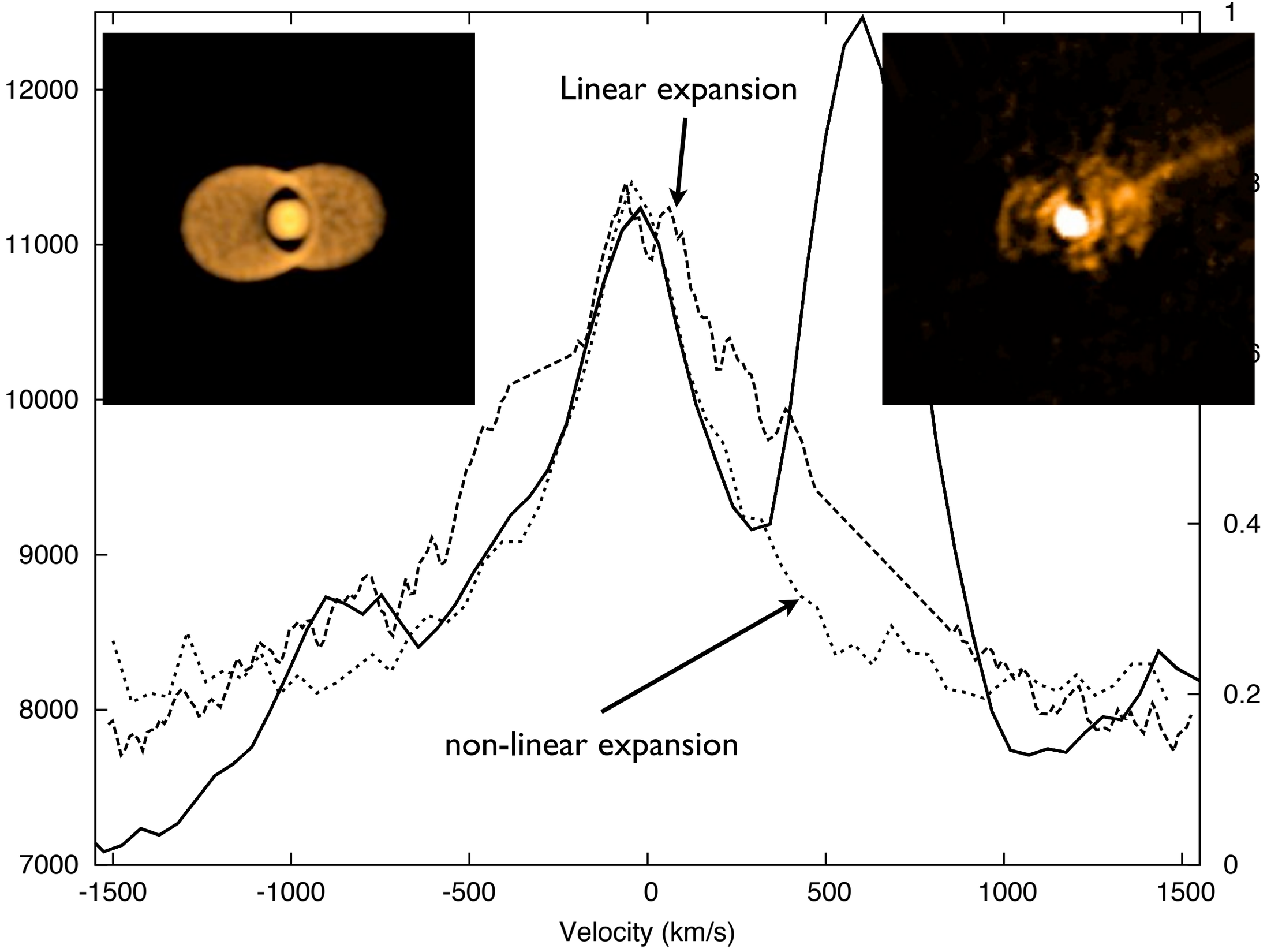
The 2nd Epoch

4.2 m WHT spectroscopic observations on 2007 April 03 (day 415 after outburst). Dispersion 0.86 Å/pix and resolution ~ 1000.

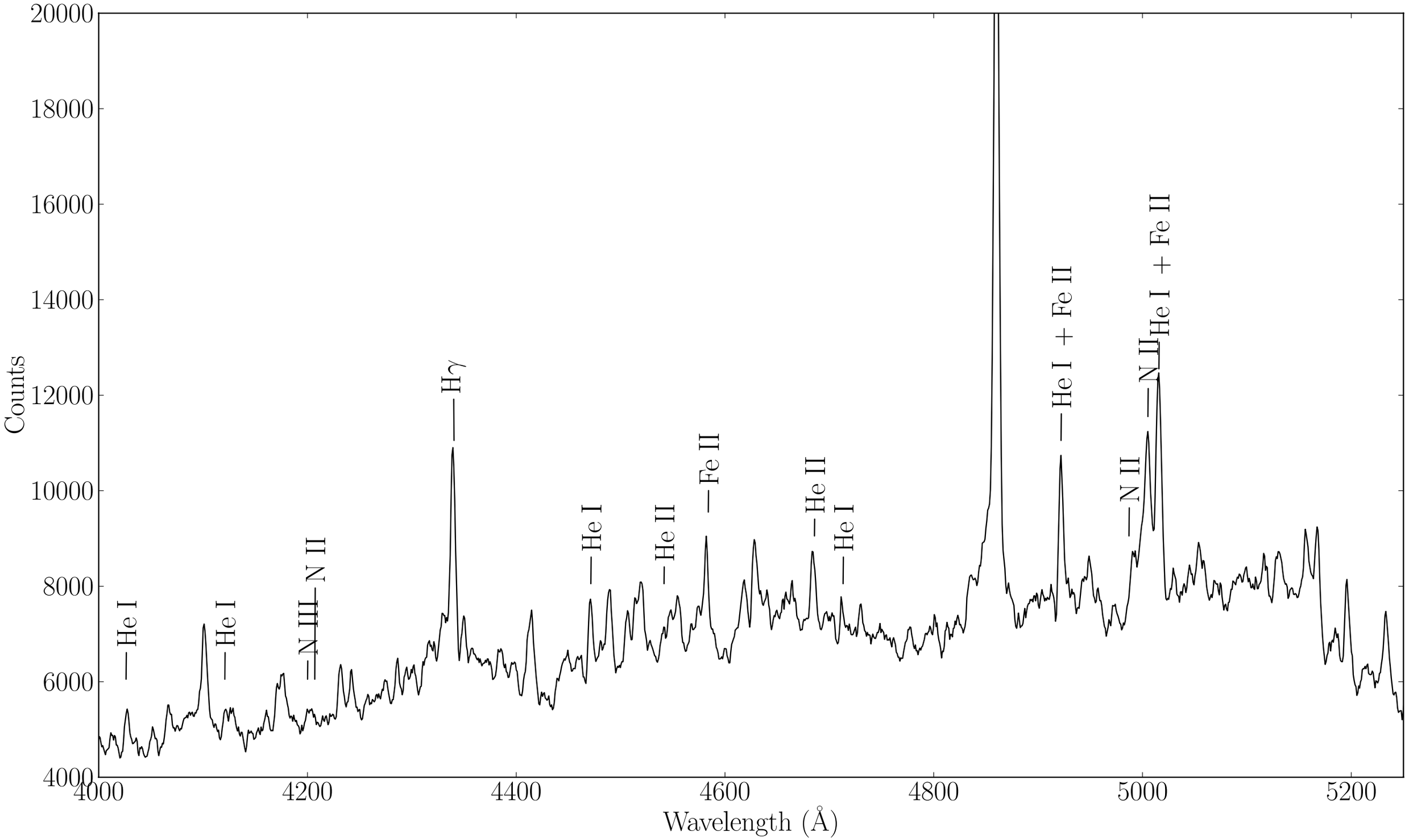



12000
11000
10000
9000
8000
7000
1
0.8
0.6
0.4
0.2
0
-1500
-1000
-500
0
500
1000
1500
Velocity (km/s)




Linear expansion
non-linear expansion
12000
11000
10000
9000
8000
7000
1
0.4
0.2
0
-1500
-1000
-500
0
500
1000
1500
Velocity (km/s)

He I - P Cyg


Counts
Wavelength (Å)
20000
18000
16000
14000
12000
10000
8000
6000
4000
4000
4200
4400
4600
4800
5000
5200
He I
He I
N III
N II
Hγ
He I
He II
Fe II
He II
He I
He I + Fe II
N II
He I

Summary

* First epoch HST observations (155 days after outburst) showed an asymmetric bipolar morphology - **due to the finite width of the HST filter**

* What is the true geometry and hence the inclination of the remnant? Is this related to the orbital inclination? **Bipolar with the west lobe nearest to the observer and an inclination of the remnant of 39+1-10 degrees (in agreement with orbital inclination from Dobrzycka & Kenyon 1994)**

* Why is the outburst bipolar? Due to interaction with red-giant wind or intrinsically bipolar? **The images and spectra are well replicated with a density enhancement in the waist of the system suggesting that the bipolarity is either due to an accretion disk around the central WD and/or interaction with the anisotropic pre-existing red-giant wind**

* What about the second epoch HST observations? **The outer high velocity components' expansion appears linear between the two epochs while the central low velocity may not have expanded linearly**

* High resolution, time resolved spectra of RS Oph could elucidate the geometry.