

HST Imaging and Ground-based Spectroscopy of the Expanding Nebular Remnant of the 2006 Outburst of RS Ophiuchi

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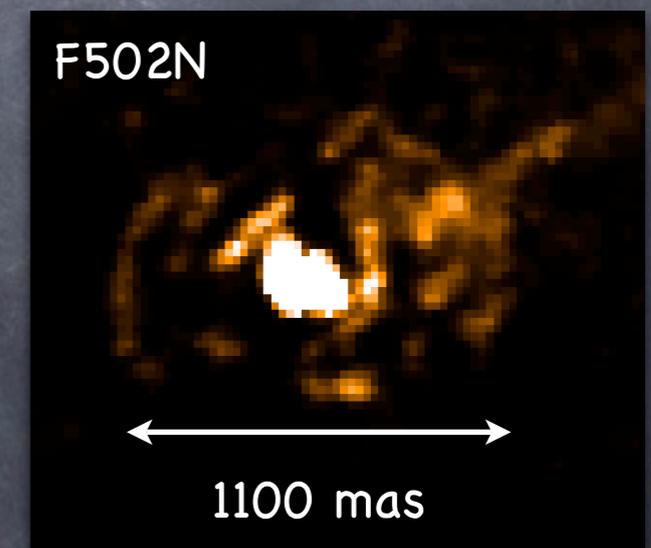
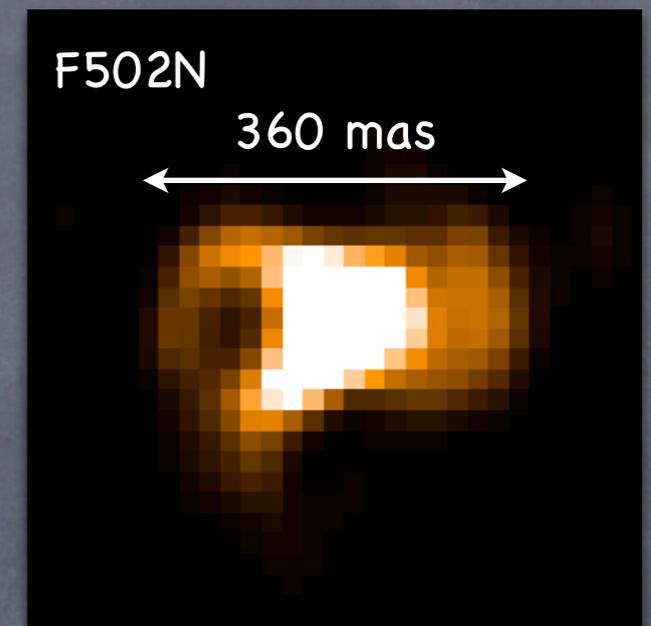
RS Oph Vital Statistics

- Recurrent Nova - previous outbursts 1898, (1907), 1933, (1945), 1958, 1967, 1985 and 2006
- $d = 1.6 \pm 0.3$ 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)

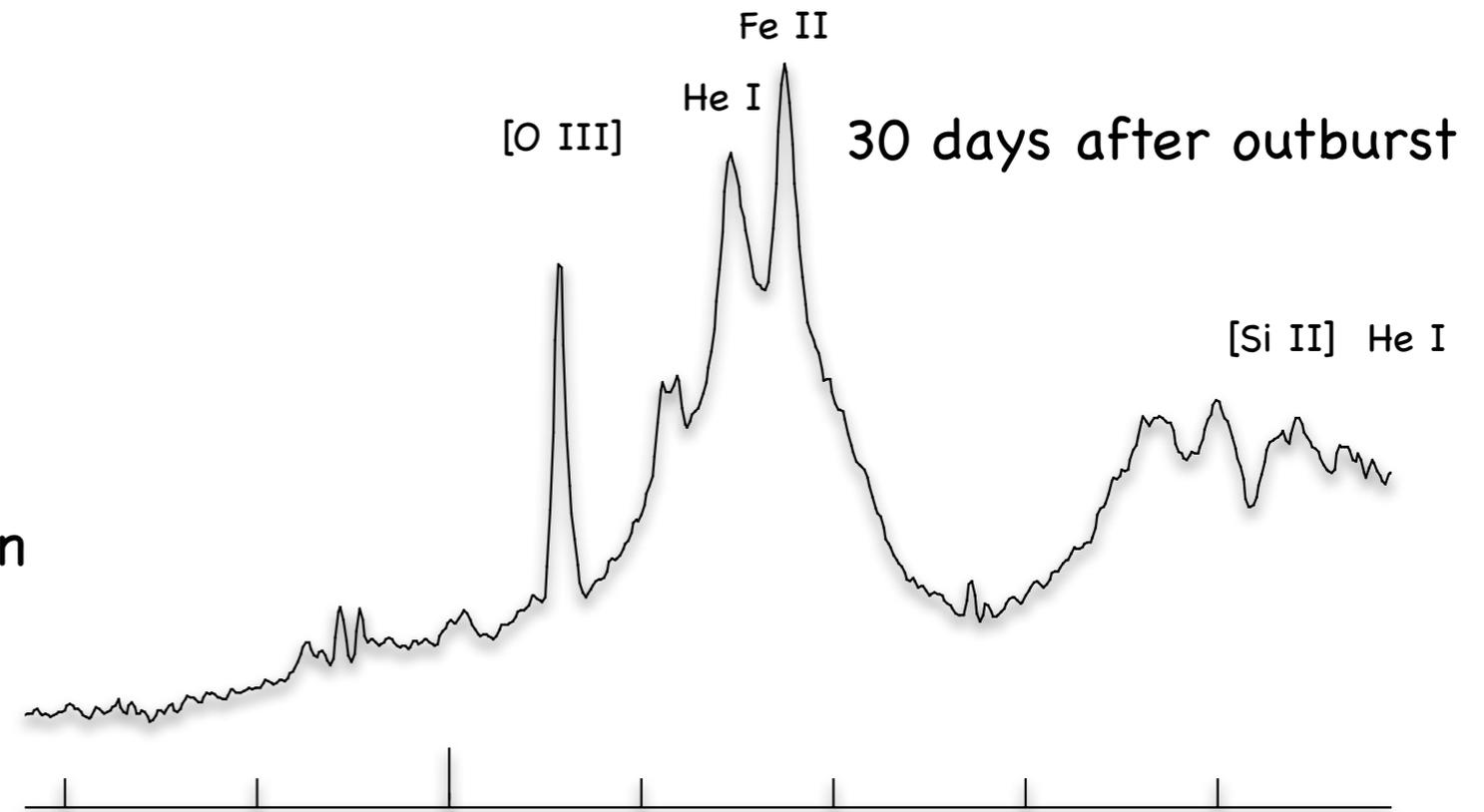
HARDY

Setting the Scene

- First epoch HST/ACS observations (155 days after outburst) showed an asymmetric bipolar morphology (Bode et al. 2007, Harman et al. 2008) $\rightarrow V = 3200$ km/s
- Why is the outburst bipolar? Due to interaction with red-giant wind or intrinsically bipolar? (Lloyd et al. 1993, O'Brien et al. 2006, Sokoloski et al. 2008) \rightarrow Can we learn anything more to explore these ideas?
- What is the true geometry and hence the inclination of the remnant? Is this related to the orbital inclination? (Dobrzycka & Kenyon 1994, Brandi et al. 2009)
- What about the second epoch HST/WFPC2 observations (449 days after outburst)?



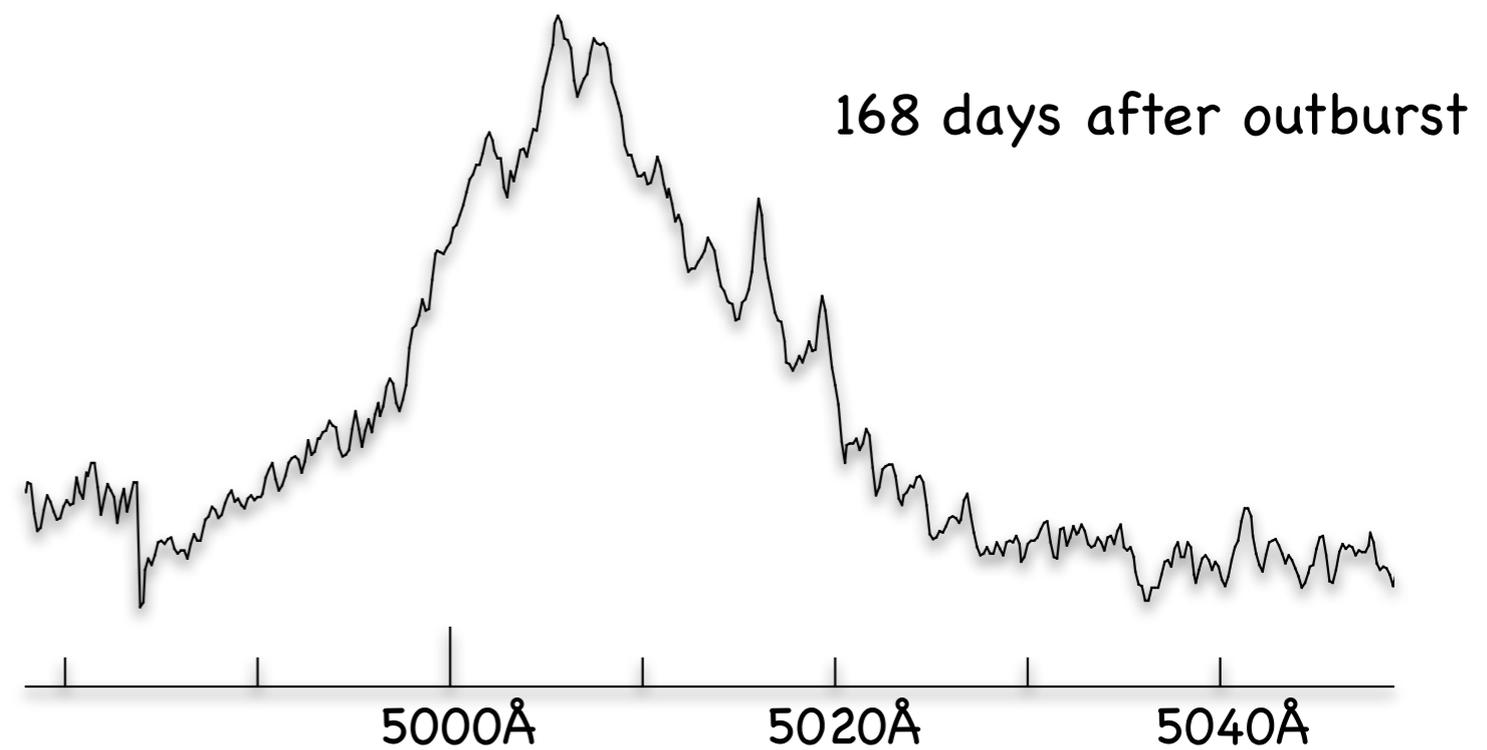
Spectra



• Observatorio Astonomico Nacional en San Pedro Martir and Observatorio Astrofisico Guillermo Haro, at Cananea

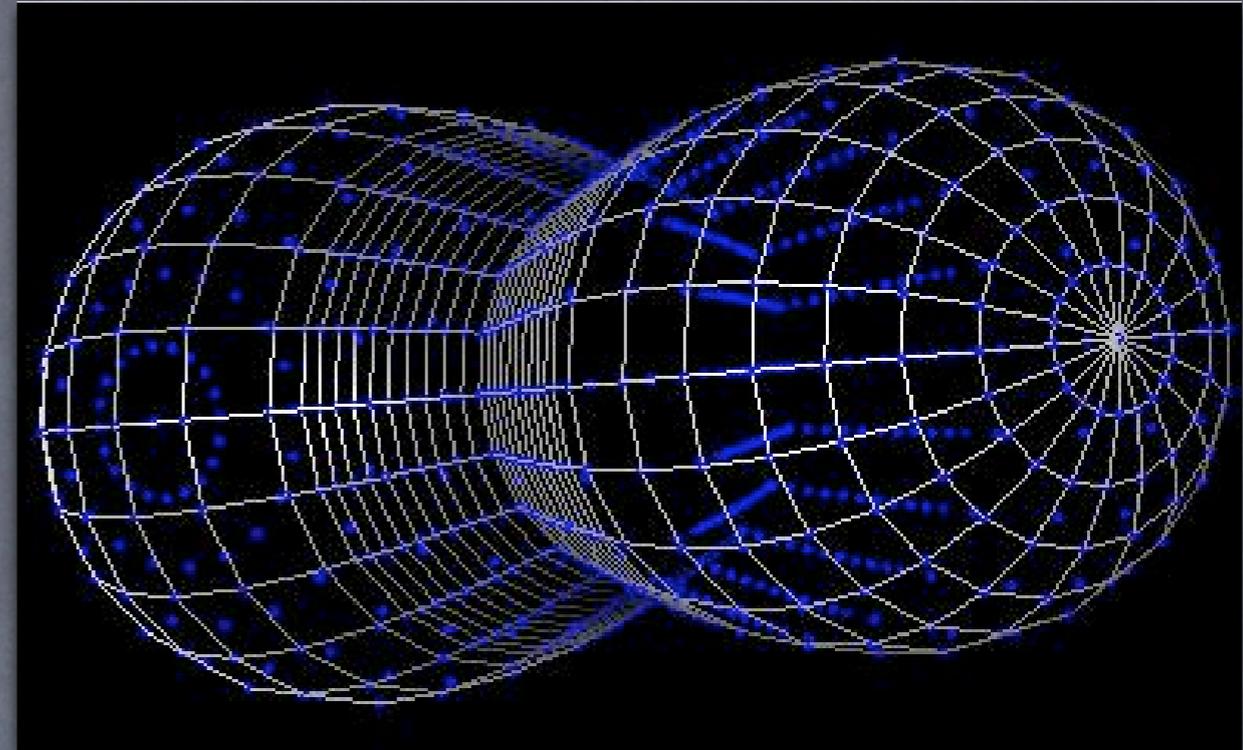
• Narrow components due to pre-existing wind

• Broad components due to high velocity ejecta/shocked wind



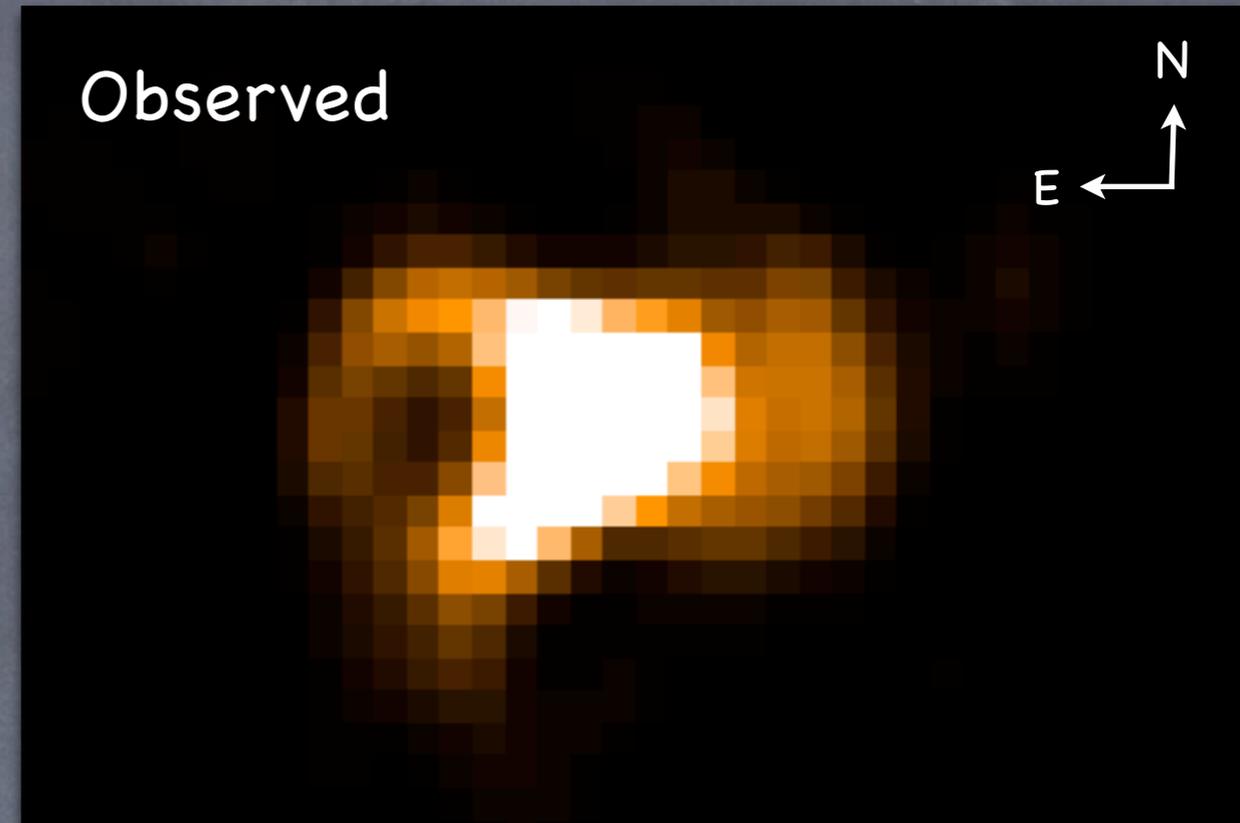
Modelling

- Modelled using Shape (Steffen & López 06)
- A tool to analyse and disentangle 3D geometry and kinematic structure of gaseous nebulae
- We adopted a Hubble flow velocity field
- Shape also allows us to model using the HST filter profile
- If modelled only with an outer dumbbell shape it produced too broad line profiles
- Slower moving material is also required

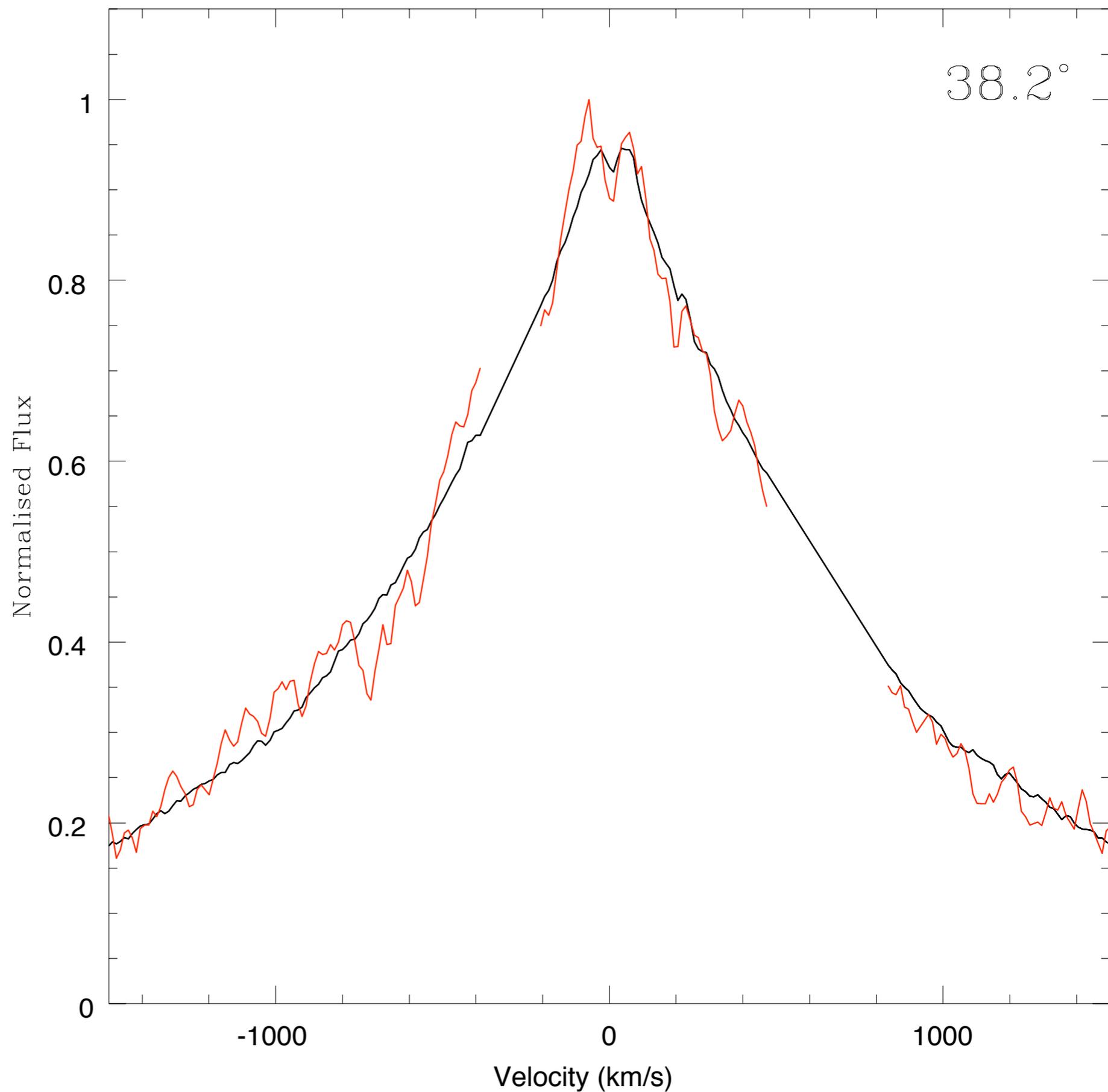


Results

- The results were well replicated with a density enhancement in the waist of the system
- The asymmetry due to the finite width of the HST filter
- This allowed us to determine the orientation of the system, where the west lobe was nearest to the observer → this contradicts the interpretation in the earlier radio observations (O'Brien et al. 2006)
- The second epoch was much harder to model, constrain and thus open to over-interpretation



With Chi-squared
minimisation we
determined the
inclination of the
system to be 38^{+2}_{-6}
degrees



Results – 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 38^{+2}_{-6} 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 leading us to suggest that the bipolarity is due to the interaction of the outburst with the anisotropic pre-existing red-giant wind**
- What about the second epoch HST observations? **The expansion appeared linear between the two epochs except possibly in the north-south extent**