Circumstellar Environments of Recurrent Novae

Valério A. R. M. Ribeiro
var@astro.livjm.ac.uk

M. F. Bode, M. J. Darnley, D. J. Harman

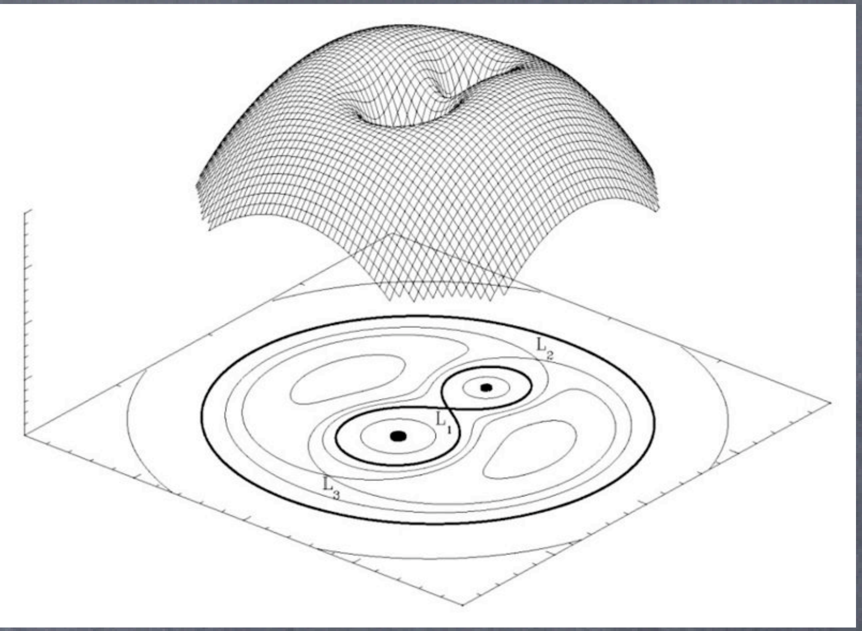
Ljubljana - 02/10/2009

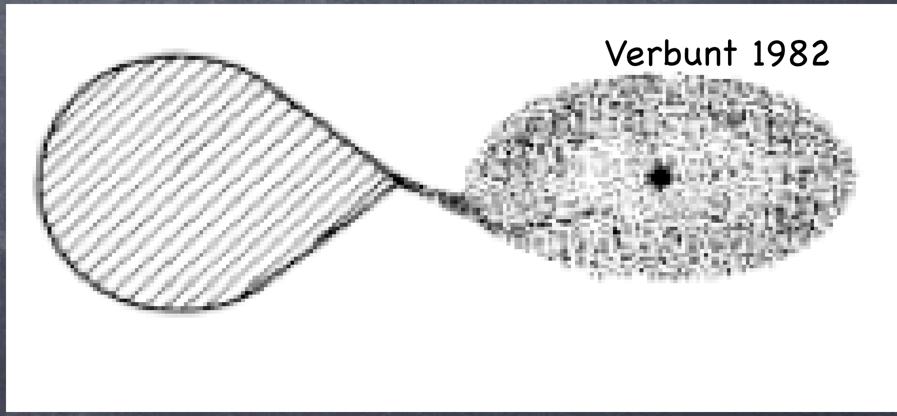
Outline

- Cataclysmic Variables
  - Classical Novae and Dwarf Novae
- Recurrent Novae
  - RS Ophiuchi
- 2006 Outburst of RS Oph
- HST imaging and ground-based spectroscopy modelling of RS Oph
- Liverpool Telescope spectroscopy of V2491 Cygni
- Summary

Cataclysmic Variables

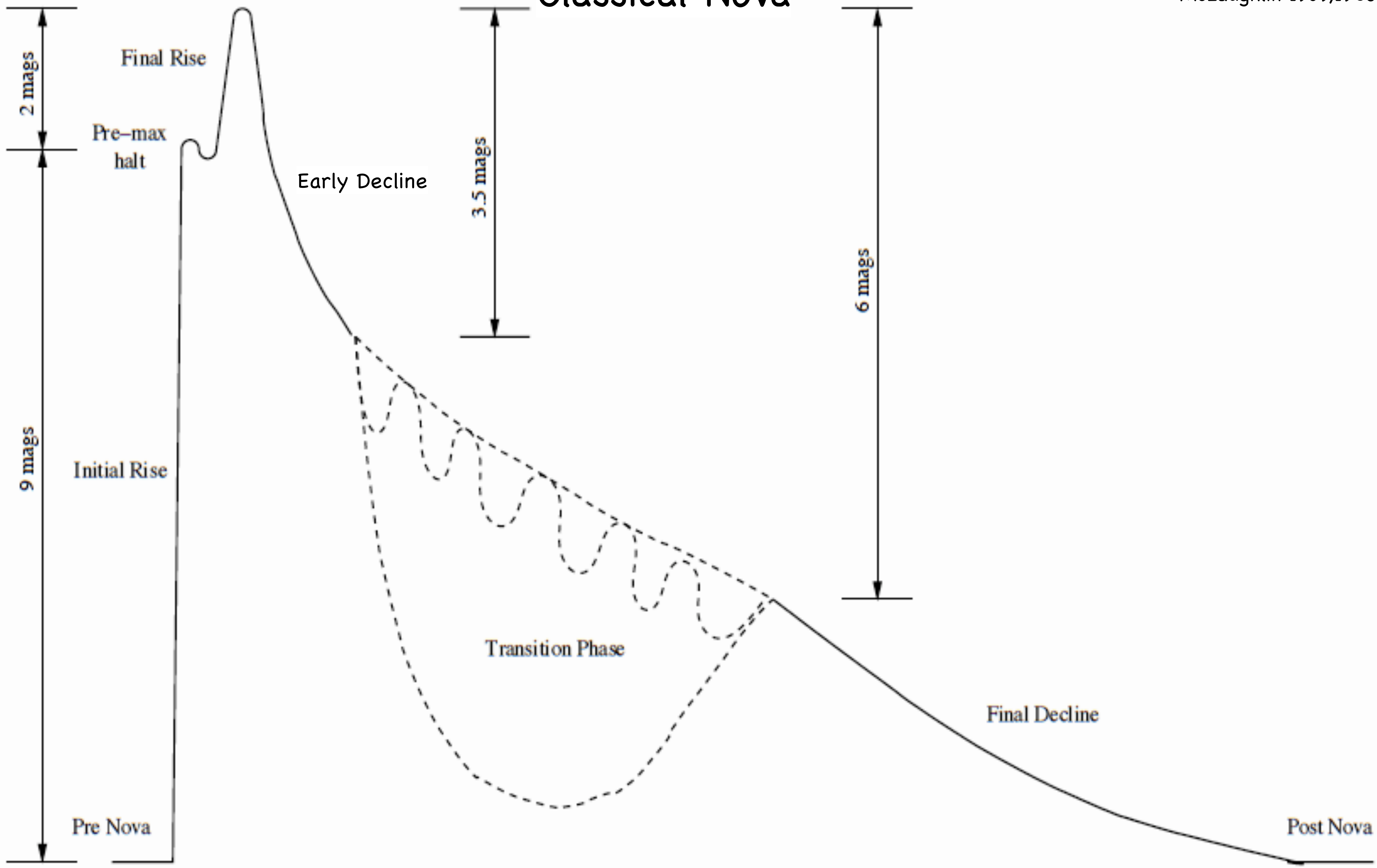
- Binary systems with WD (primary) and a Roche lobe filling star (secondary)
- Secondary accretes matter to the primary via L1
- The accreted matter, mainly H, goes into an orbit around the WD forming an accretion disk
- If the temperature and density is high enough at the base of the accreted H layer fusion occurs leading to thermonuclear runaway (Classical Nova)
- If there is a temporary large increase in the rate of mass transfer through the disc then a release of gravitational energy is possible (Dwarf Nova)





Classical Nova

McLaughlin 1939,1960



Recurrent Nova

- Sub-class of Classical Nova explosions
- WD massive - perhaps close to Chandrasekhar limit
- Two groups, according to period:
  - Long - T CrB, RS Oph, V3890 Sgr and V745 Sco
  - Short - U Sco, V394 CrA, T Pyx, CI Alq, V2487 Oph and IM Nor (and V2491 Cyg?)
- Long period - red giant secondary, high rate of mass transfer (Warner 2008)
- Short period - subgiant secondary (Warner 2008)
- These systems are strong SN Ia candidates

RS Oph Vital Statistics

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

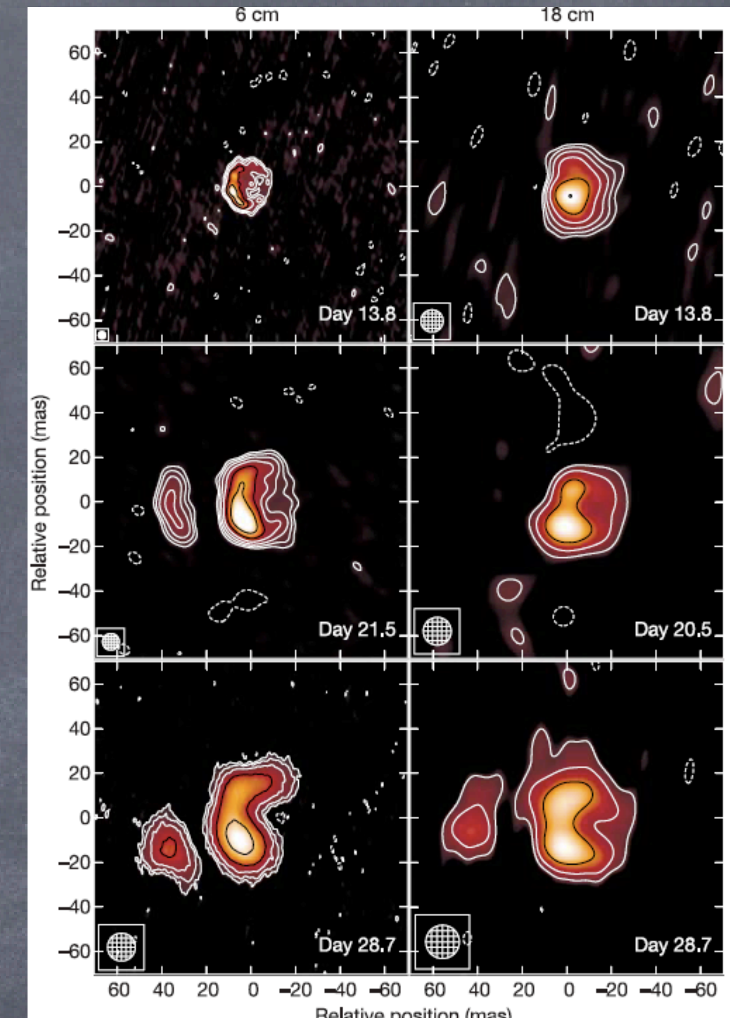
2006 Outburst

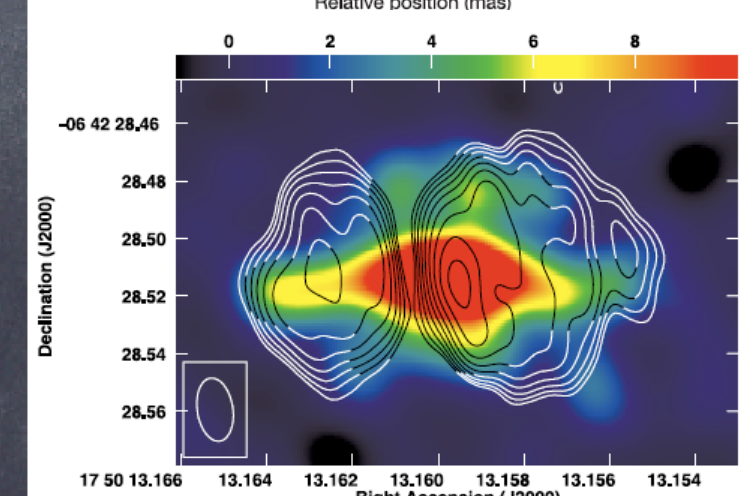
- Outburst on February 12.83 (Narumi et al. 2004; t = 0)
- Optical light curve began a rapid decline, consistent with those previously observed (Rosino 1987; www.aavso.org)
- Hα presented FWHM = 3930 km/s at t = 1.37 (Buil 2006)
- The red giant in the binary means that high-velocity ejecta run into a dense circumstellar medium, setting up shock systems
- Bode et al. 2006 calculated for a shock velocity of 4000 km/s a gas temperature of 2.2×10^8 K was derived

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 jets (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

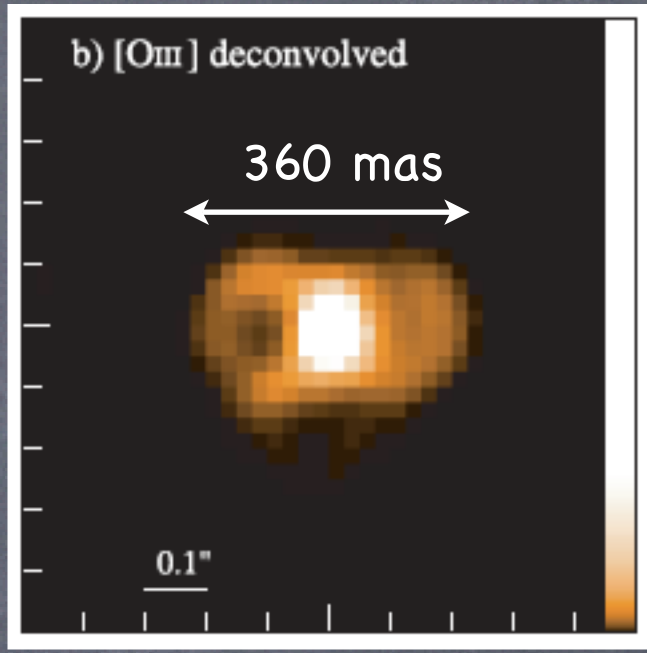


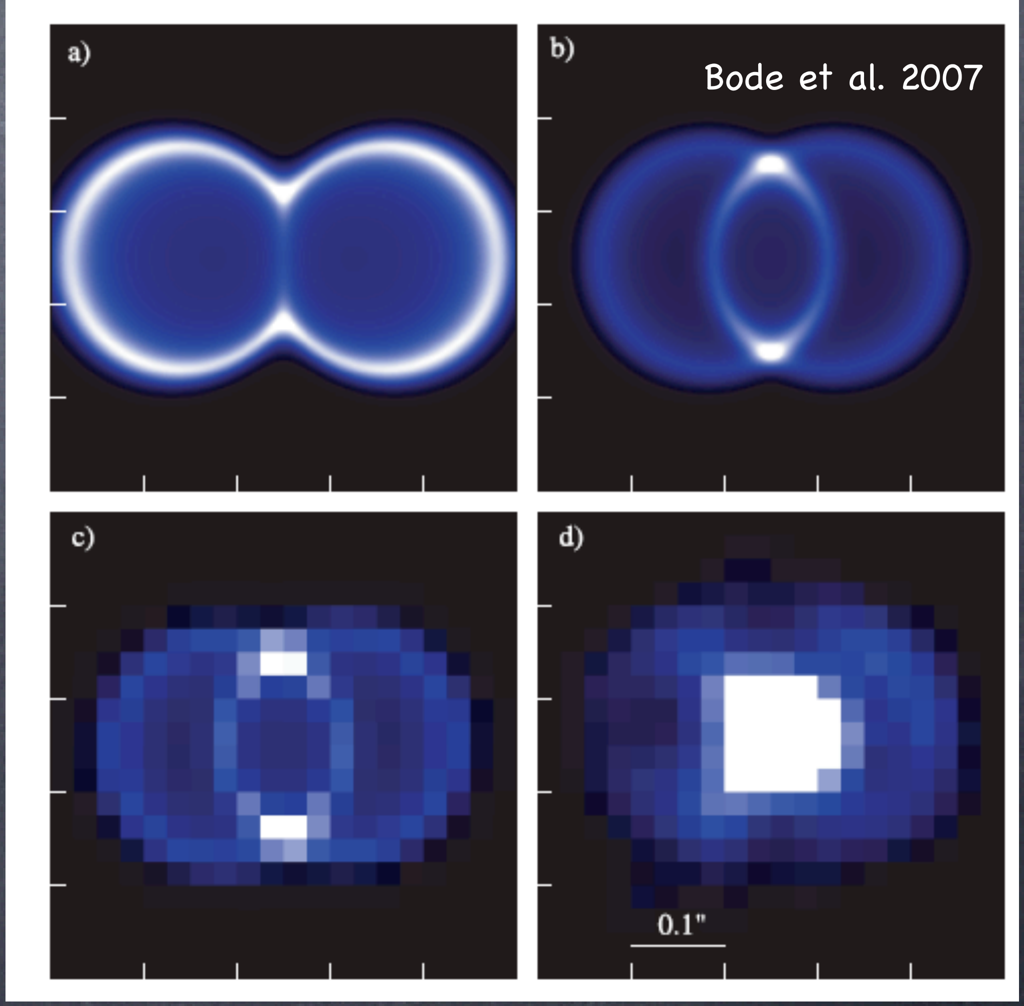


Sokoloski et al. 2008

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 be 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

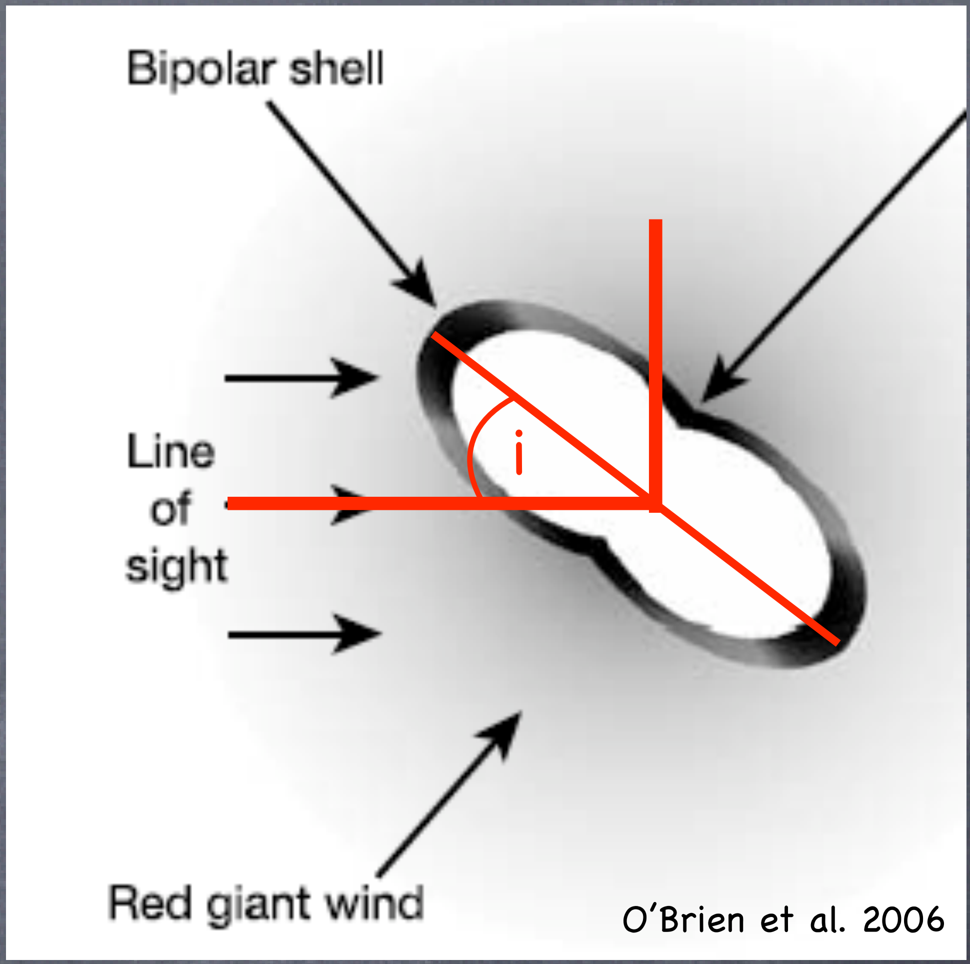




Why is the [O III] image asymmetric? Why is outburst bipolar?

2006 Outburst

- Dobrzycka & Kenyon 1994 and Brandi et al. 2009 from spectroscopic orbits derive orbital inclinations of 30-40 deg and 49-52 deg
- HST observations taken 449 days after outburst had not yet been fully analysed

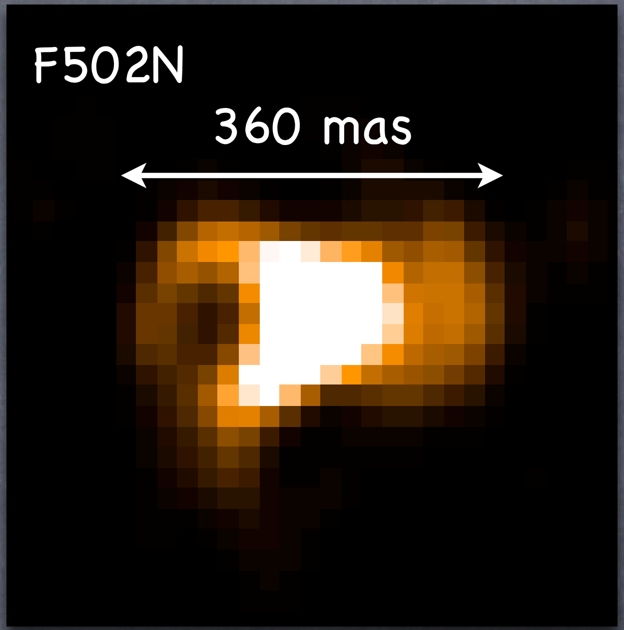


What is the true geometry and hence the inclination of the system?

Can we learn anything more from the second epoch HST observations

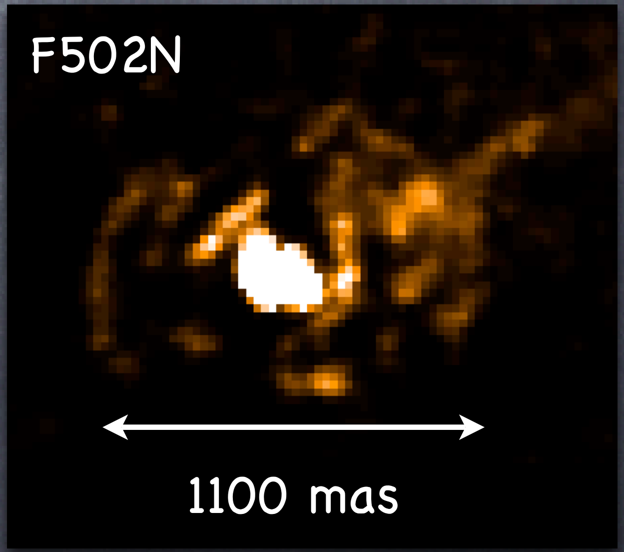
HST imaging

- We reanalysed HST/ACS 155 days after outburst and complemented with HST/WFPC2 observations taken 449 days after outburst. Both observations taken with the narrow-band filter F502N



- First epoch results consistent with Bode et al. 2007; V_t = 3200 km/s (East-West) and 1300 km/s (North-South)

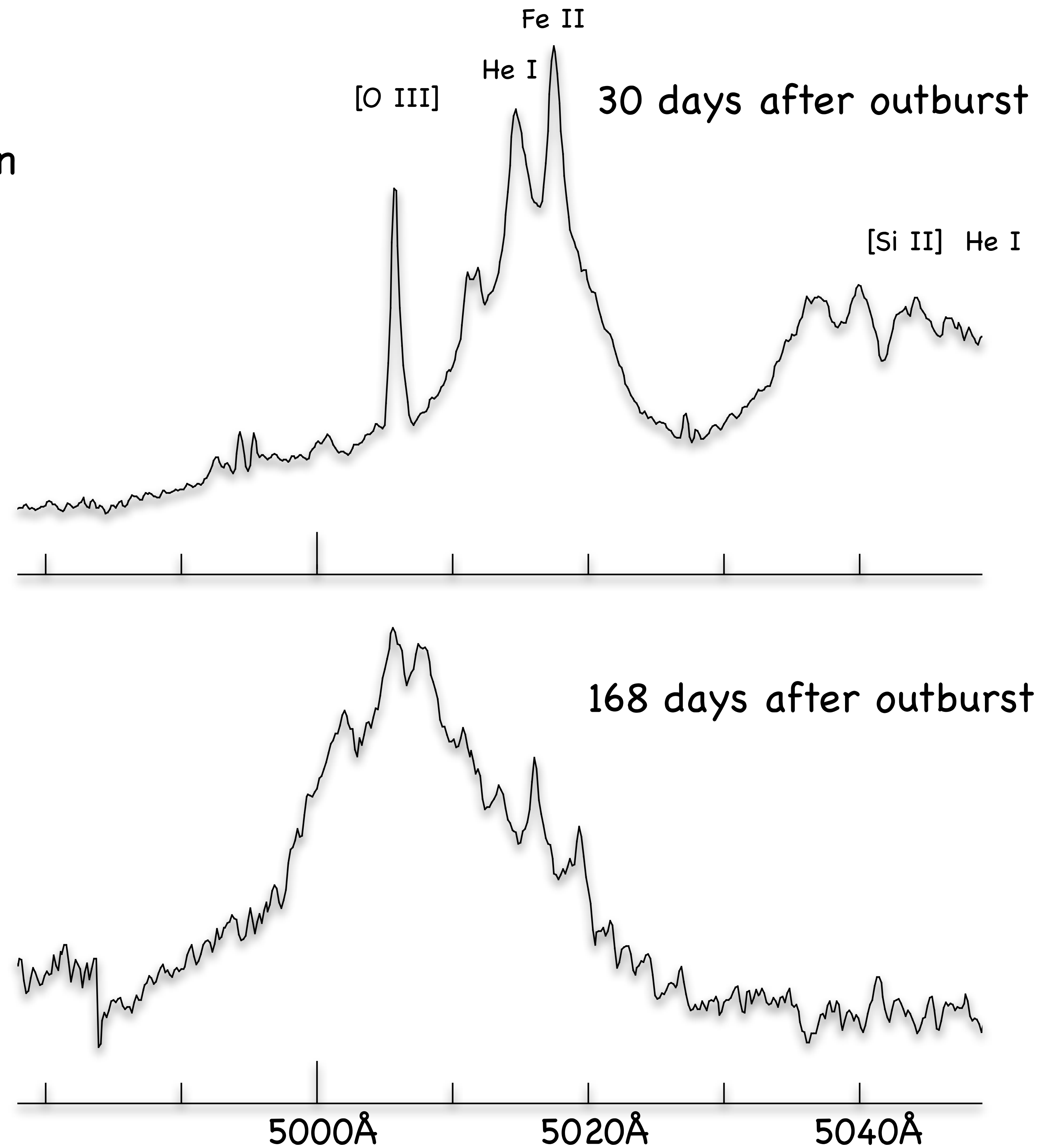
- Second epoch results implied no deceleration in both E-W and N-S extents; although because of the poorer quality of the WFPC2 camera it is harder to say anything about the N-S extent



- We also derived the extent for the red-giant wind as 2.6×10^{15} cm. The E-W extent has cleared the wind by the first epoch observations

Spectra

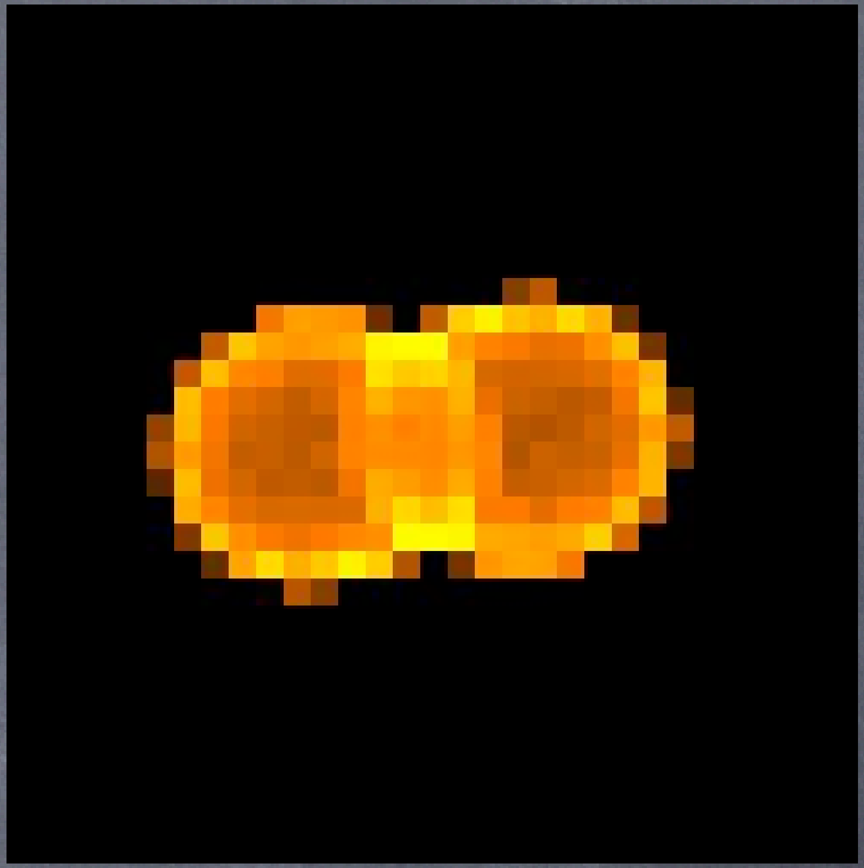
- Observatorio Astonomico Nacional en San Pedro Martir and Observatorio Astrofisico Guillermo Haro, at Cananea
- Observations both with high and low resolution spectra
- Low resolution spectra showed that this outburst was consistent with previous ones
- High resolution spectra was to be used to model the system
- Narrow components due to pre-existing wind
- Broad components due to high velocity ejecta/shocked wind



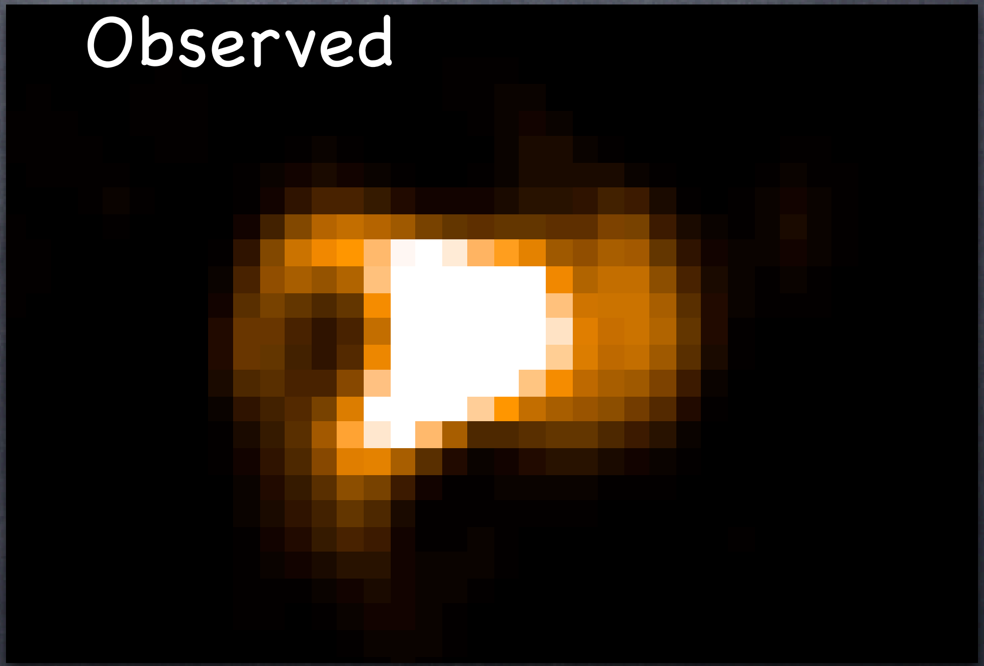
Modelling

- 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:

$$V_{\rm exp} = \frac{3200}{\sin i}\frac{r}{r_0}\ {\rm km\ s^{-1}}$$

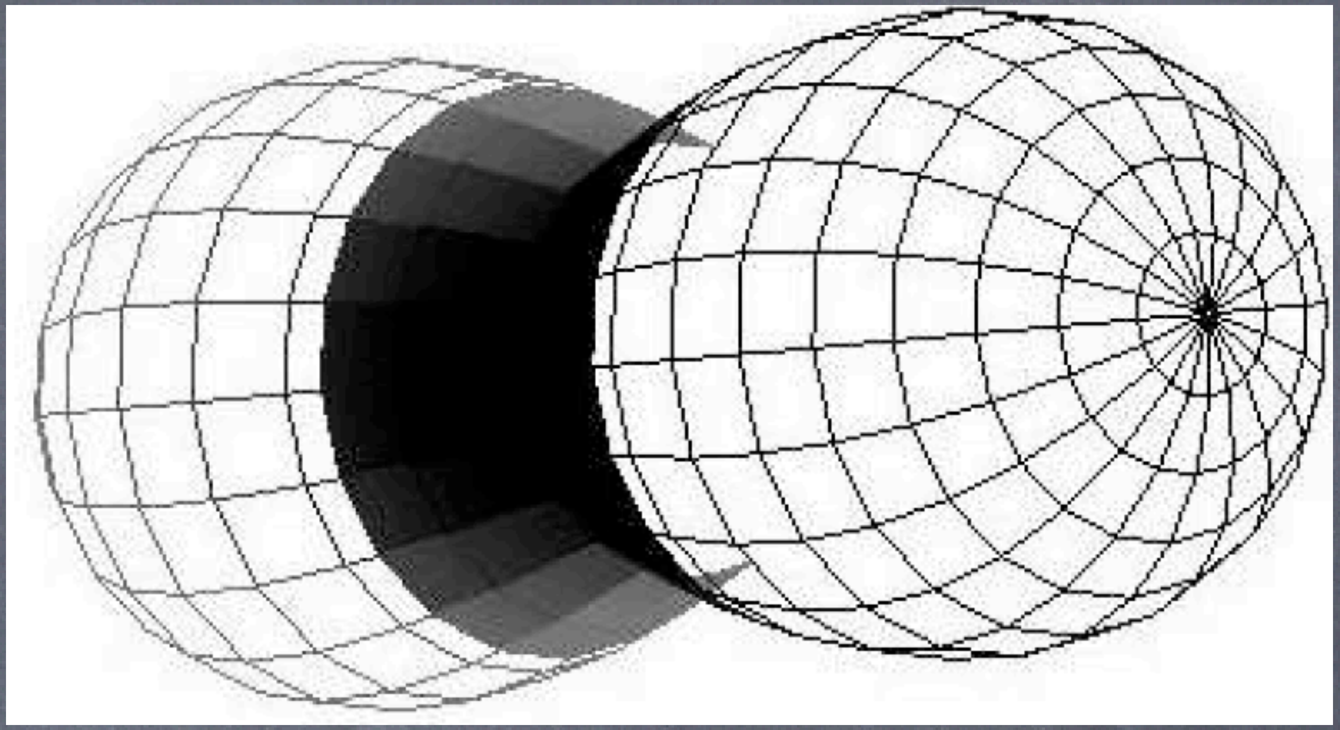


- Started with a simple bipolar structure as modelled by other authors (O'Brien et al 2006; Bode et al. 2007)
- Our initial modelling suggested that the structure was not a simple bipolar, it produced too broad line profiles



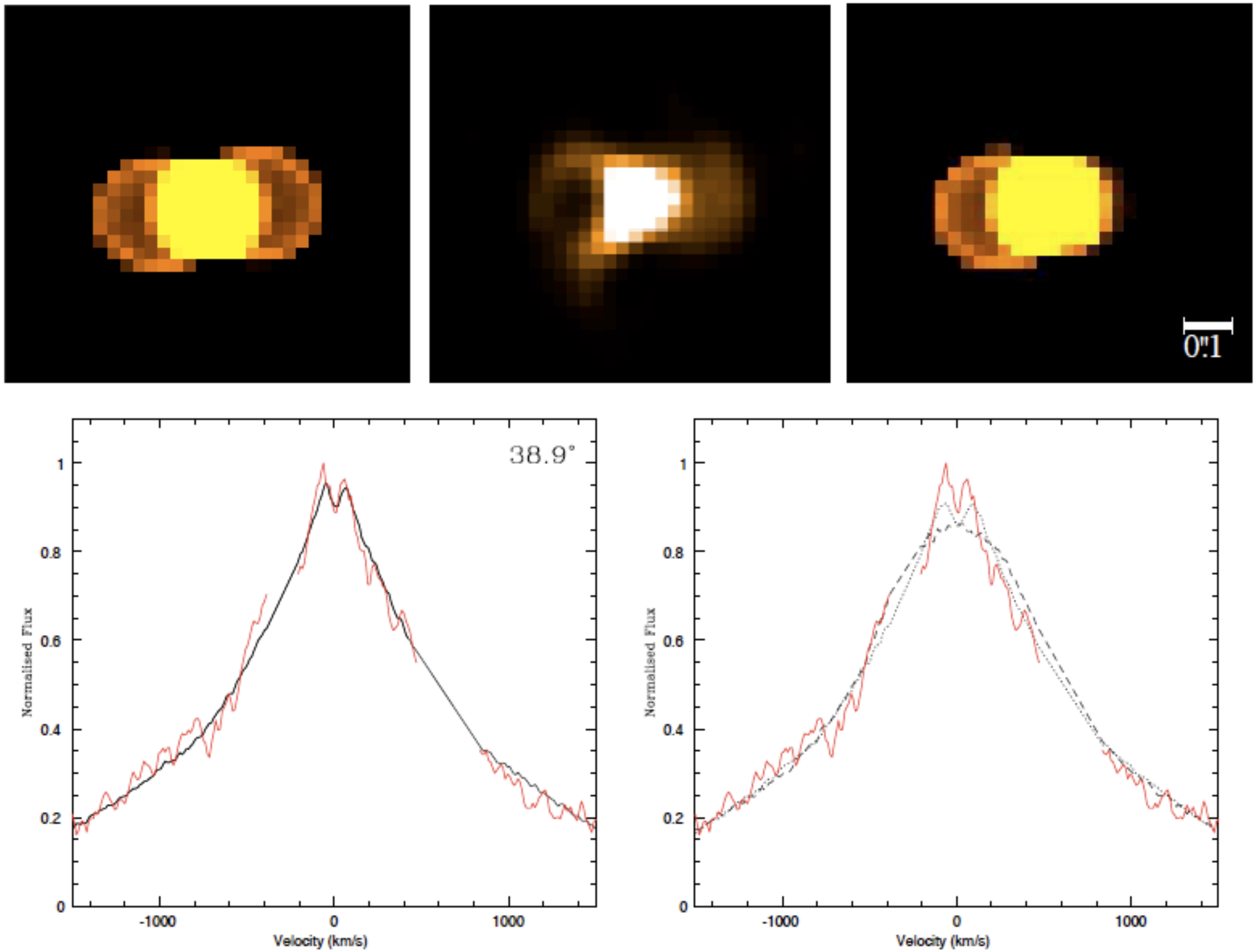
Modelling

- Some authors modelled the outburst by means of Gaussian fitting to line profiles, with different components interpreted as arising from different regions of the expanding remnant (Skopal et al. 2008; Banerjee et al 2009)

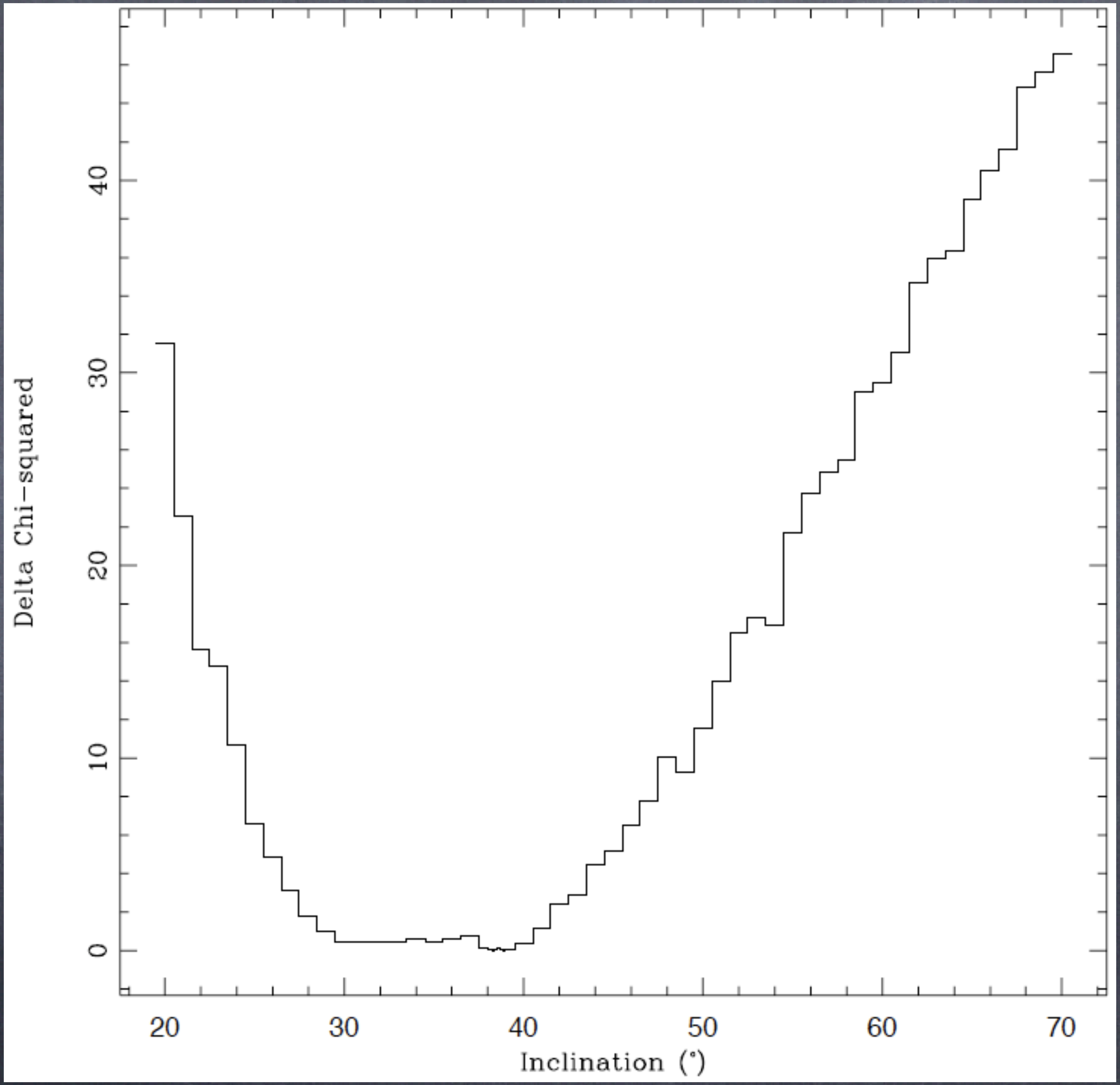


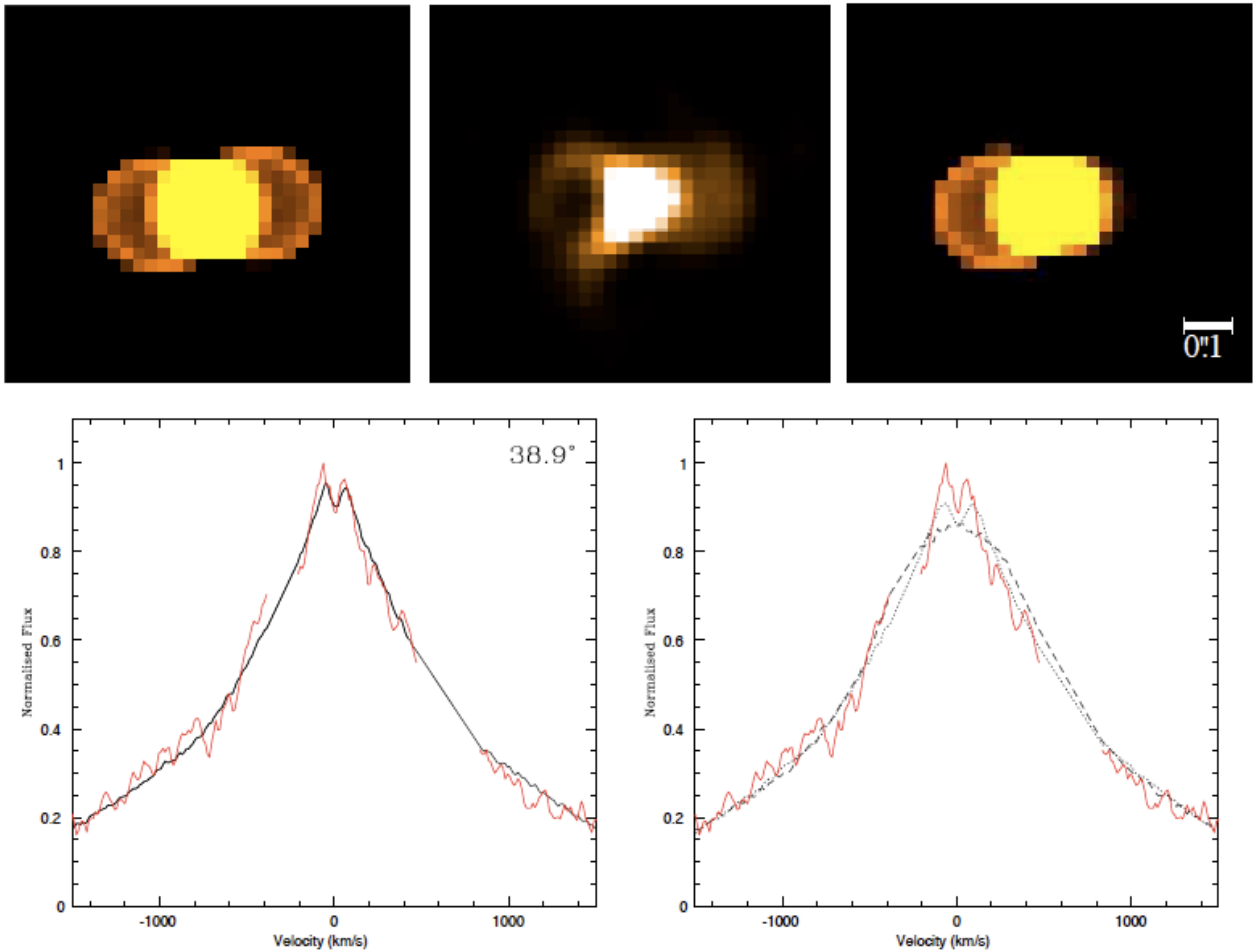
- Slower moving material is also required; we therefore model a dumbbell (outer) and hour glass (inner) structure

- The hour glass is 4 times denser than the dumbbell

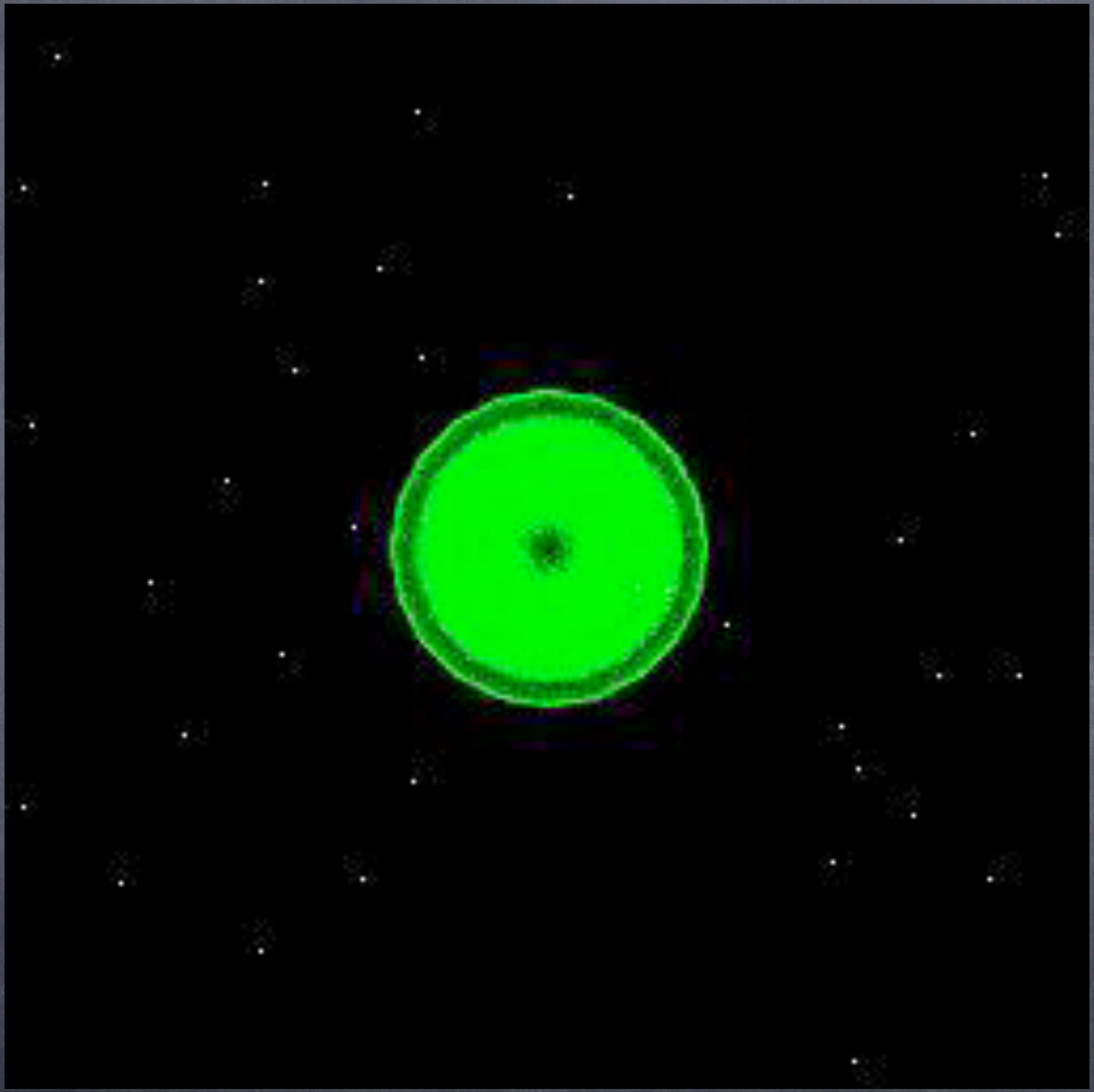


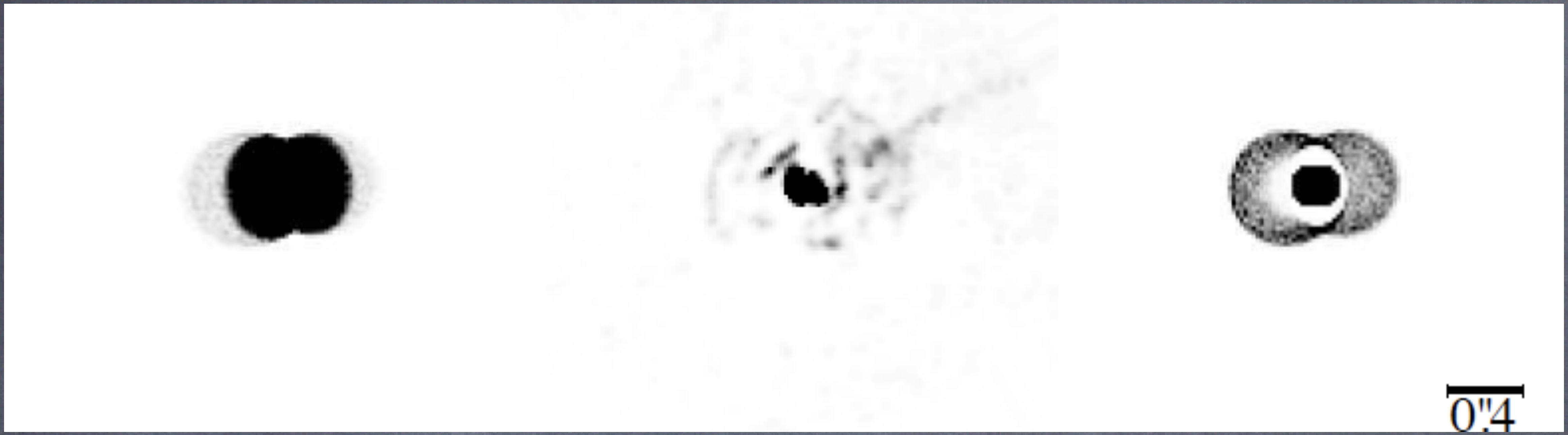
0.″1
38.9°
Normalised Flux
Velocity (km/s)


Delta Chi-squared
0
10
20
30
40
20
30
40
50
60
70
Inclination (°)



0.″1
38.9°
Normalised Flux
Velocity (km/s)
-1000
0
1000
0
0.2
0.4
0.6
0.8
1





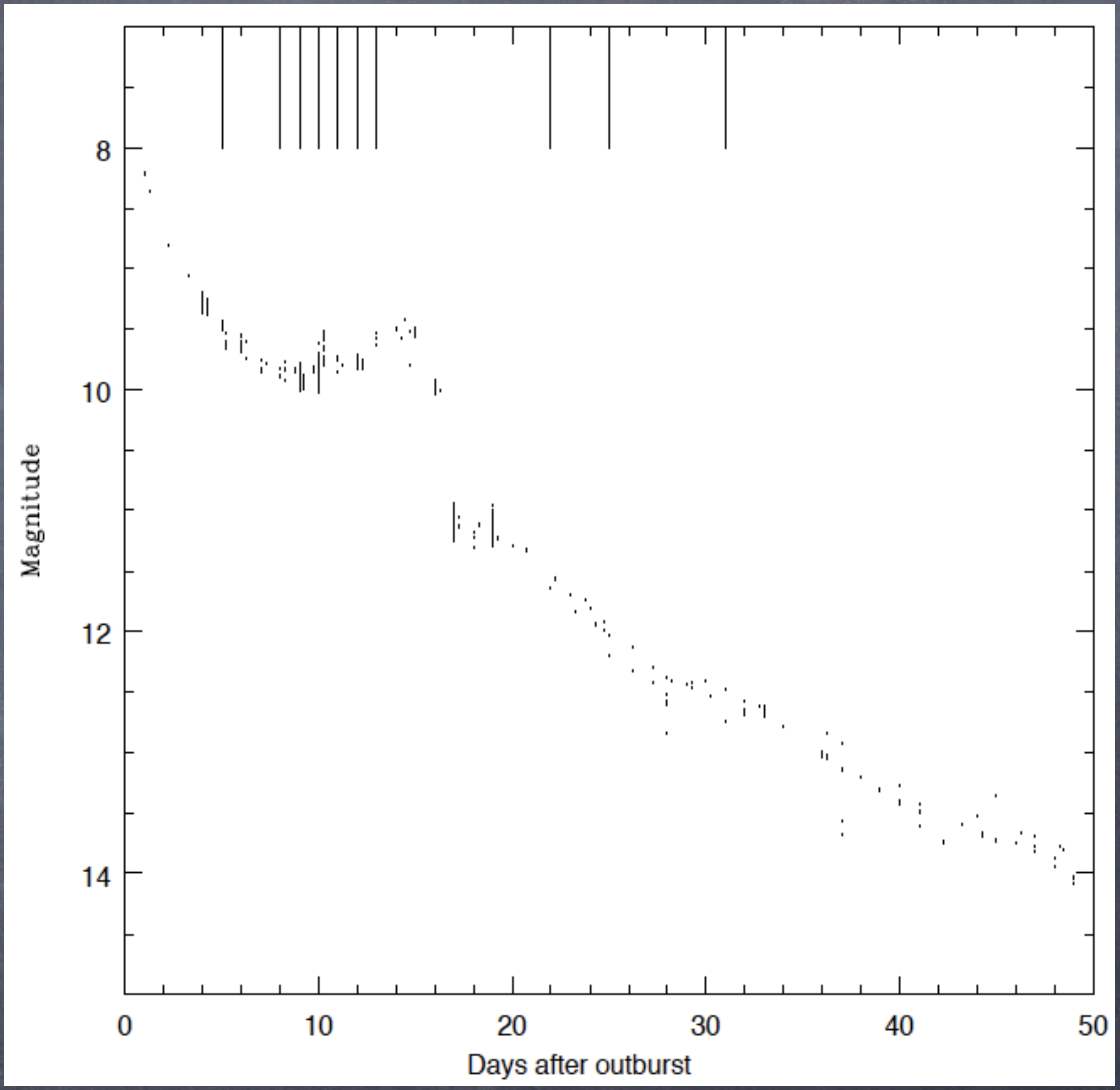
- The second epoch was much harder to model, constrain and thus open to over-interpretation
- The model implies that the outer structure underwent a linear expansion; however, there is more evidence of deceleration for the central region

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 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 expansion appeared linear between the two epochs except possibly in the north-south extent**

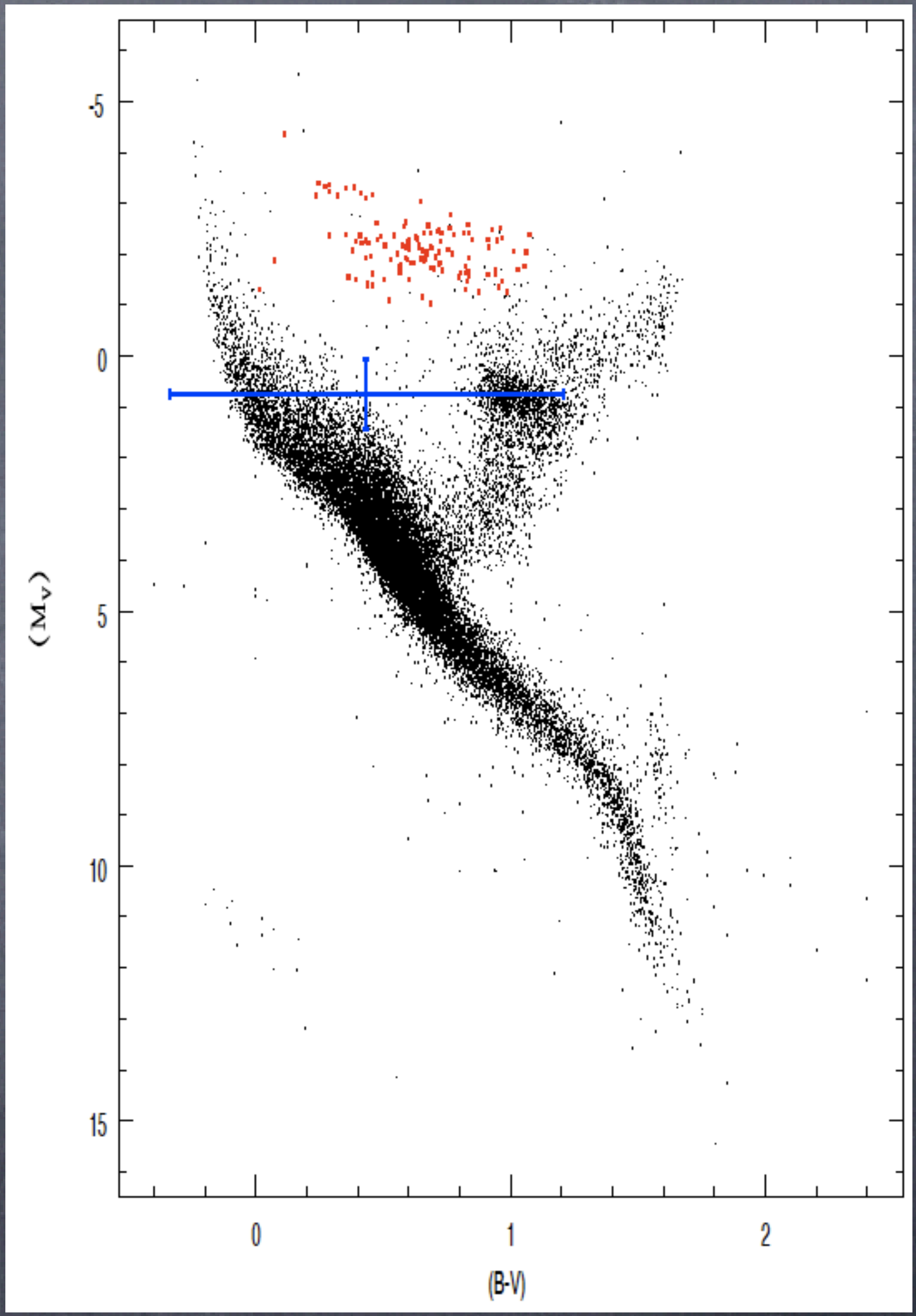
V2491 Cyg

- Discovered on 2008 April 10.8 (Nakano et al. 2008)
- Hα FWHM ≥ 4500 km/s (Ayani & Matsumoto 2008; Lynch et al. 2008)
- Estimated distance of 10.5 kpc (Helton et al. 2008)
- Orbital period of just over 2 hours (Baklanov et al. 2008)
- Re-brightening suggested to be due to release of energy from magnetic activity on WD (Hachisu & Kato 2009)
- However, if magnetic then hard X-ray spectral change should be of the order of the orbital period (Ibarra et al. 2009; Page et al. 2009)



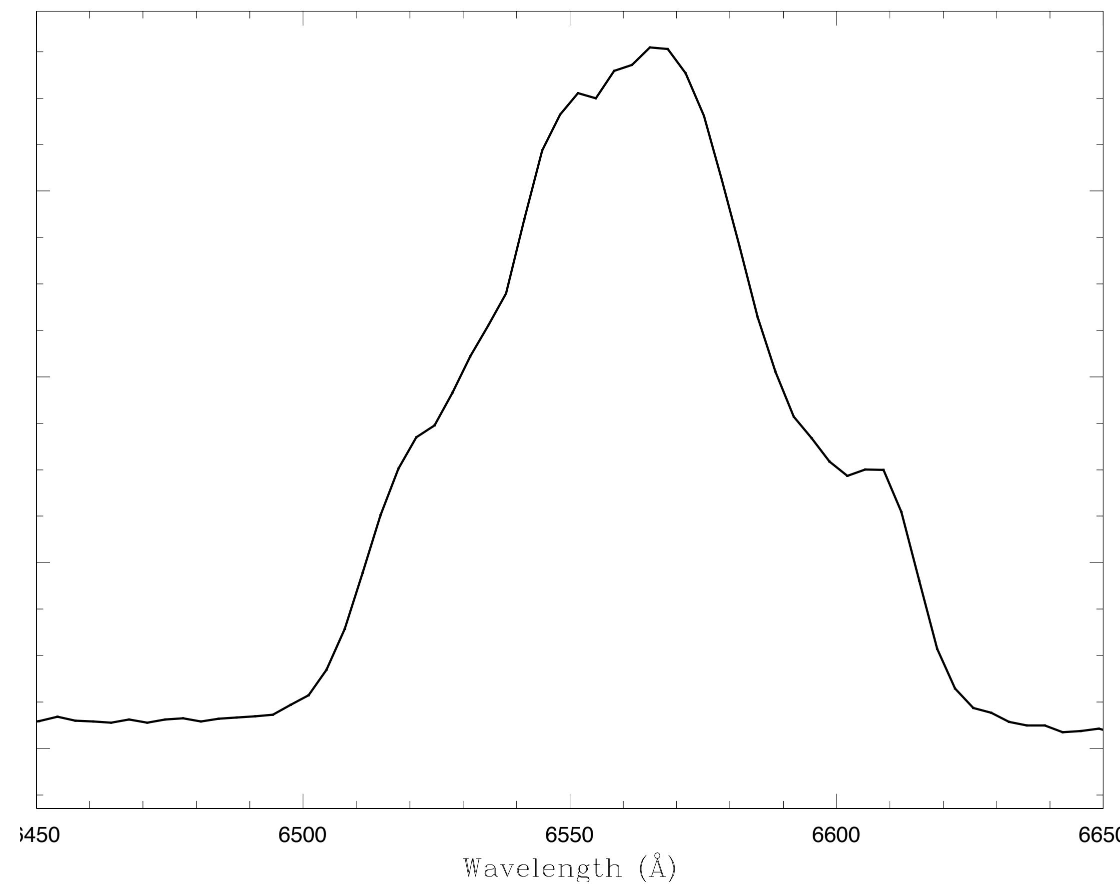
V2491 Cyg

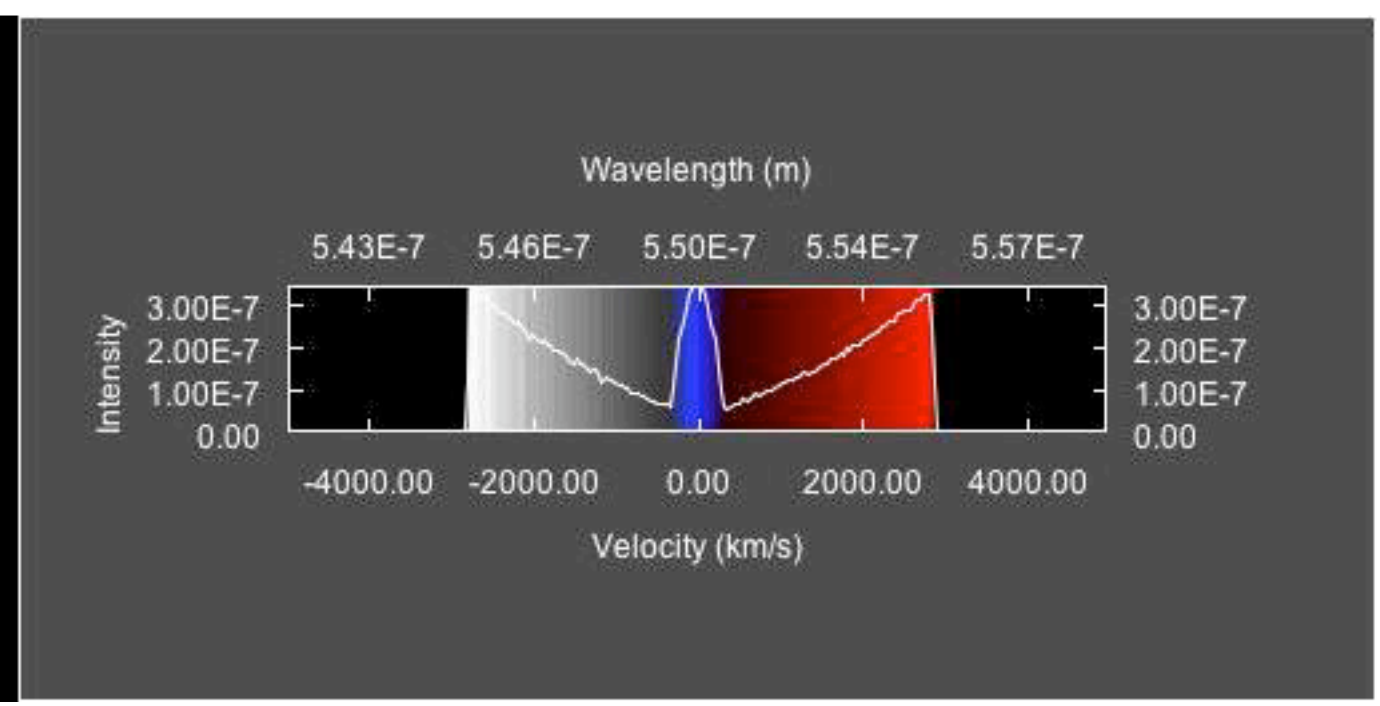
- Suggested strong RN candidate due to its similarity with other RNe, U Sco and V394 CrA (Tomov et al. 2008) and because of the presense of a pre-outburst X-ray source (e.g. Ibarra & Kuulkers 2008)
- Previously only one other nova presented pre-outburst x-ray emission (V2487 Oph)
- Possible recurrence period of 100 years (Ibarra et al. 2009)
- IR data do not show considerable decrease in line profile widths (Naik et al. 2009)



LT Spectroscopy

- Meaburn Spectrograph (decommissioned) observations taken 5 to 31 days after outburst
- Looking at Hα evolution with the aim of modelling the late time spectra
- This is not a very well constrained model because of the lack of imaging
- Modelling will include similar systems as RS Oph (bipolar expansion with density enhancement) and HR Del (polar blobs and equatorial rings; Hutchings 1972, Solf 1983)





Overall Conclusions

- RS Oph; a system with a red giant secondary - dumbbell and a hour glass structure with 4 times the density

- V2491 Cyg; a system with most likely a MS star - initial models suggest that the system comprises of polar blobs and an equatorial ring

- The next task with V2491 Cyg is to constrain the model spectra with that of the observed and see how the different parameters, e.g. size of object and velocity, affect the overall results

- The question of how the bipolarity is formed is still open, do systems with a red giant form differently to those with sub-giants/MS stars?

Ribeiro et al. 2009, ApJ, 703, 1955

var@astro.livjm.ac.uk