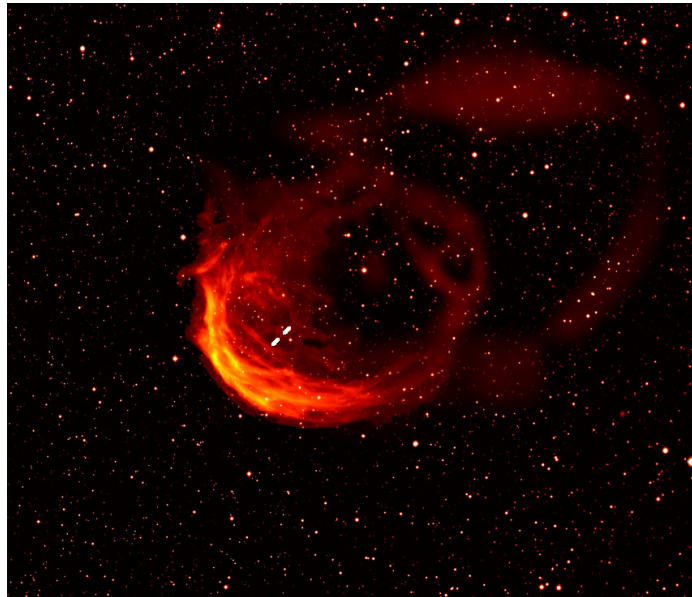


Rebrightening of planetary nebulae through ISM interaction

MASH PNe workshop 2009

Tuesday 17th February



Chris Wareing



UNIVERSITY OF LEEDS



Overview

How do planetary nebulae die?

- The traditional model
- The effect of movement through the ISM
- Four stages of PN-ISM interaction
- Recent simulations

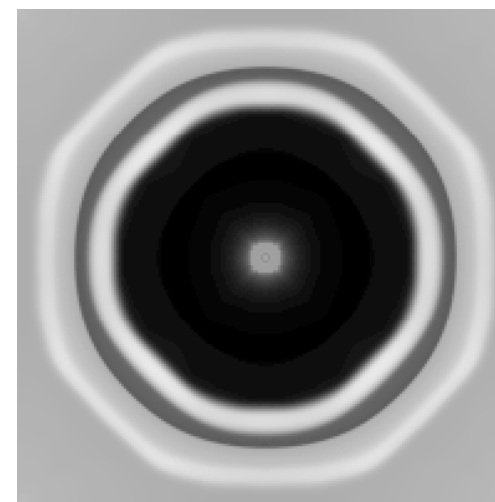
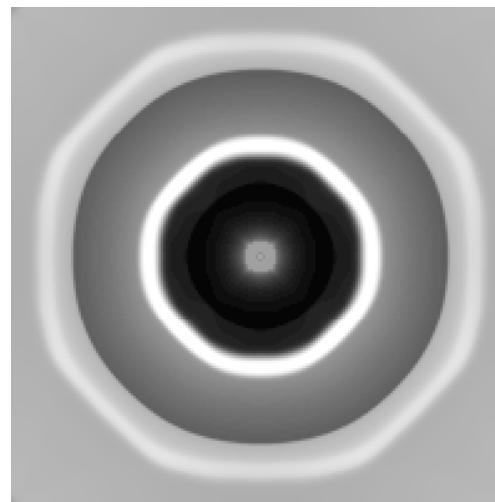
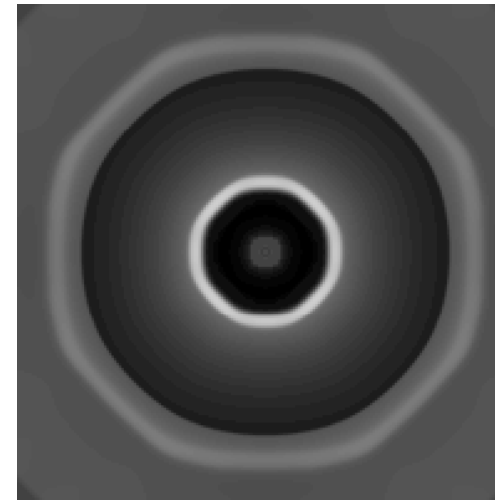
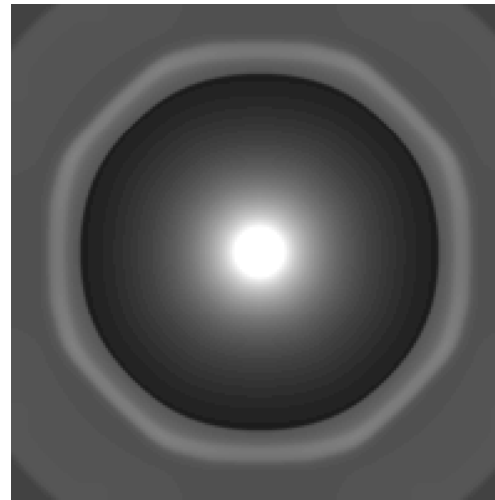
Collaboration: Albert Zijlstra, Tim O'Brien,
Myfanwy Bryce, Neil Vaytet





The traditional model

- PN expands into a symmetric wind-blown bubble of AGB wind.



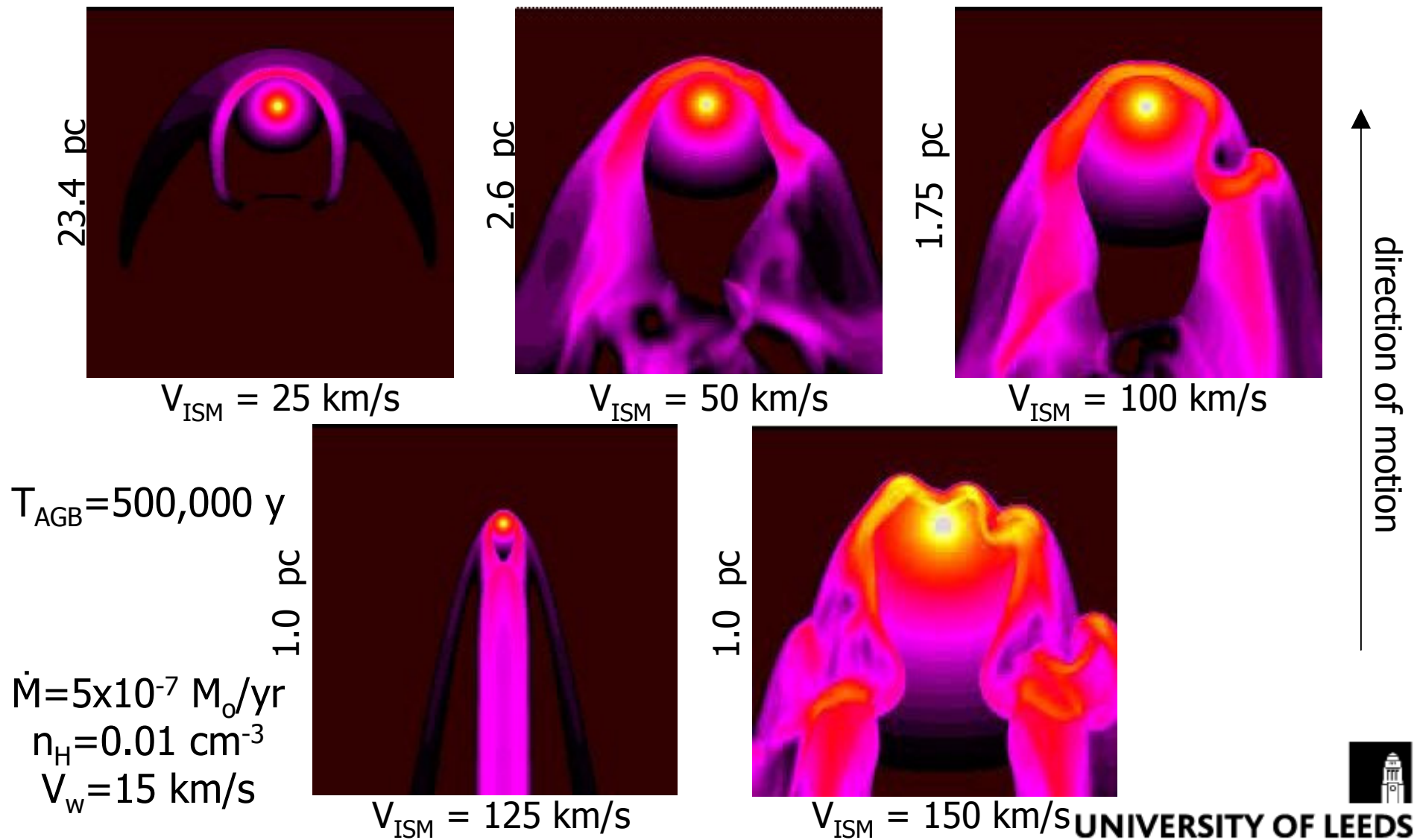
2.0 pc

$$\dot{M} = 10^{-6} M_{\odot}/\text{yr}, \quad n_{\text{H}} = 1 \text{ cm}^{-3}, \quad v_{\text{w}} = 15 \text{ km/s}$$



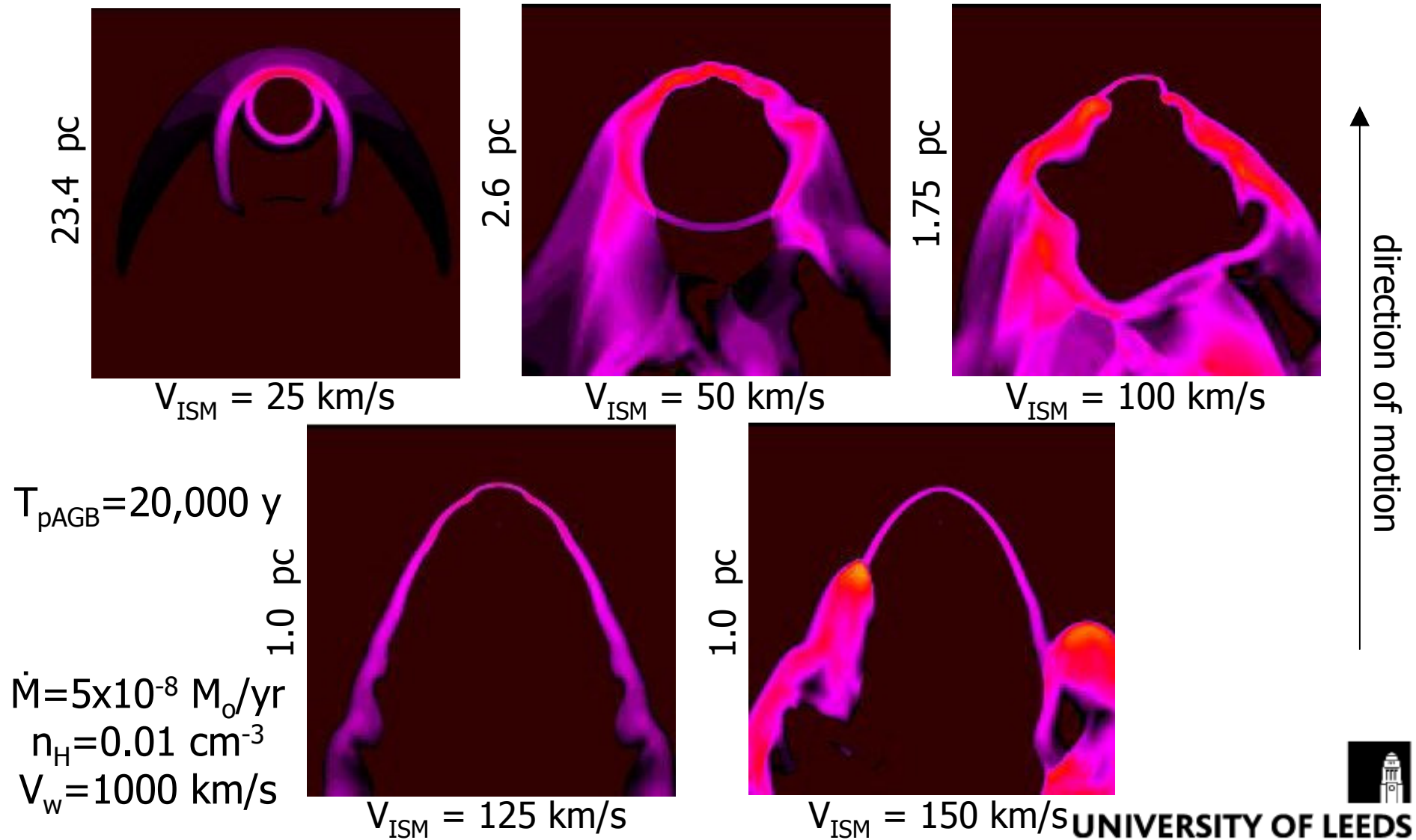


Movement through the ISM; the AGB





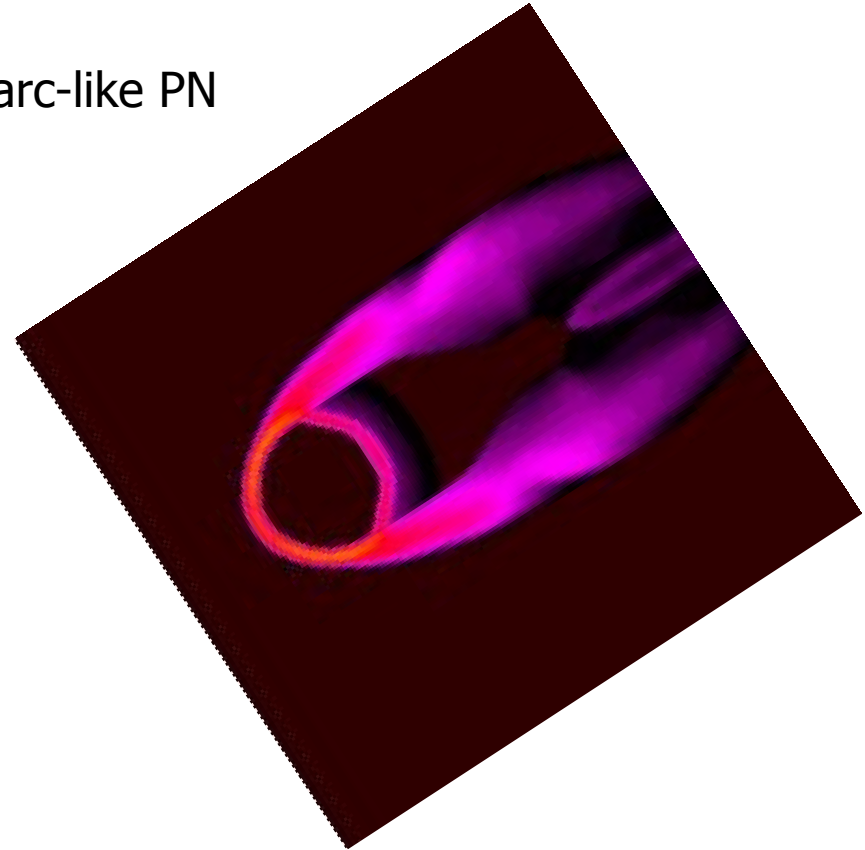
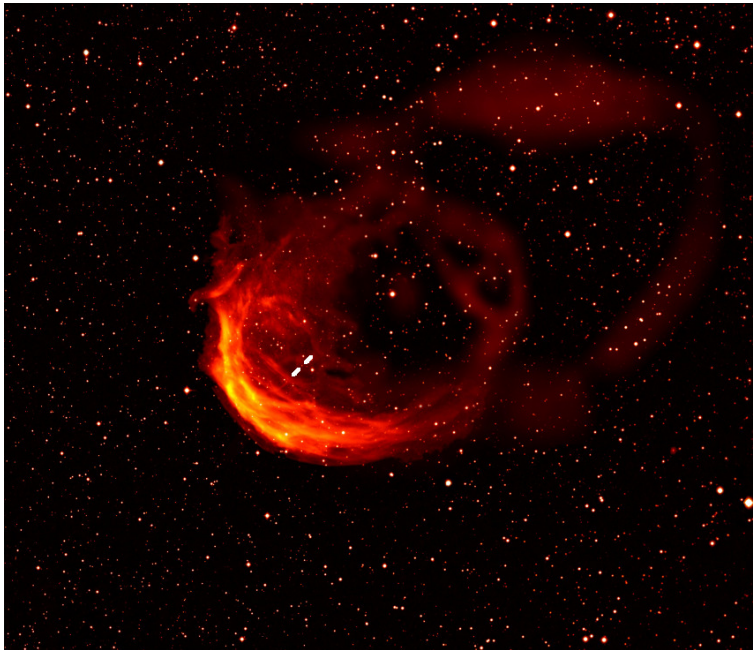
The post-AGB / PN phase





Sh 2-188

Initially thought to be a bright one-sided arc-like PN



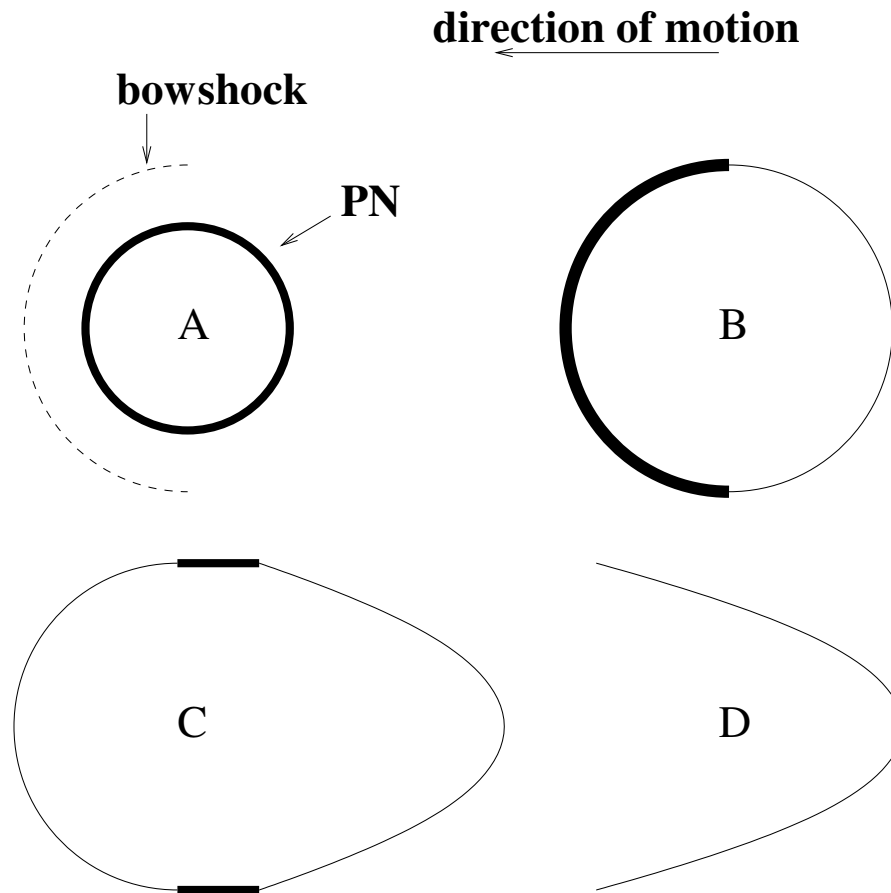
IPHAS images revealed faint structure – a circular completion of the arc and a tail

**Sh 2-188 is a case of strong PN-ISM interaction,
revealed by IPHAS**





Generalisation of the interaction



Stage 1 – PN as yet unaffected by the interaction but a faint bow shock may be observable (A)

Stage 2 – PN shell is brightened in the direction of motion (B).

Stage 3 – the geometric centre of the nebula shifts downstream away from the central star (C).

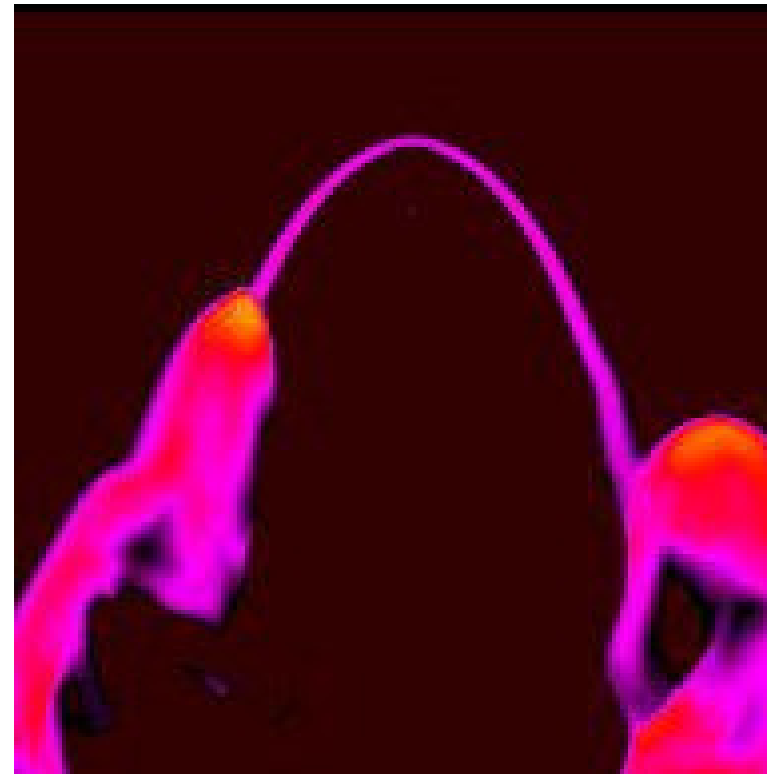
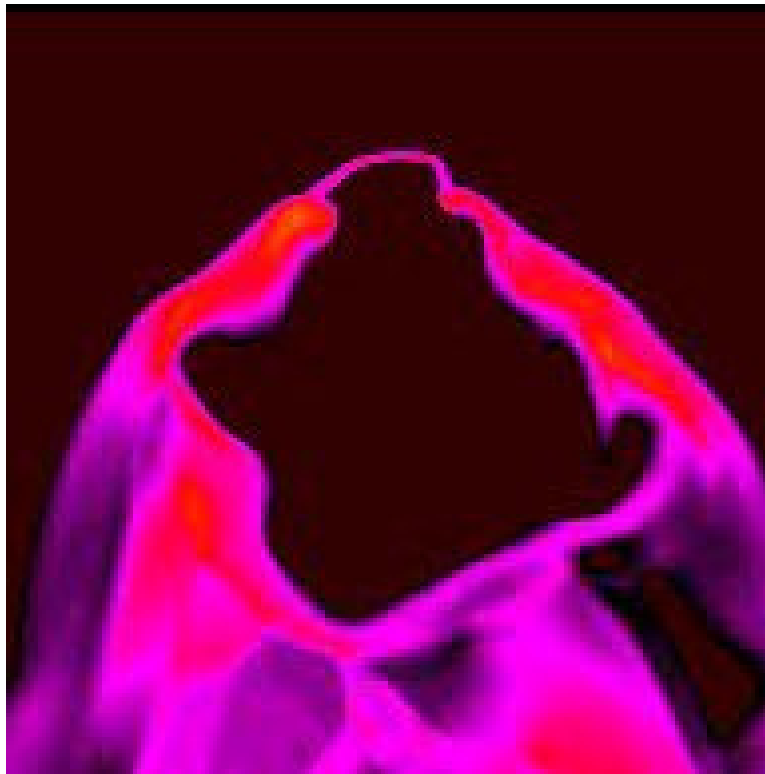
Stage 4 – the PN is completely disrupted; central star can now appear outside its nebula (D).

Modelling of the AGB phase of evolution is crucial
PN-ISM interaction is not limited to ancient PNe





Extreme cases

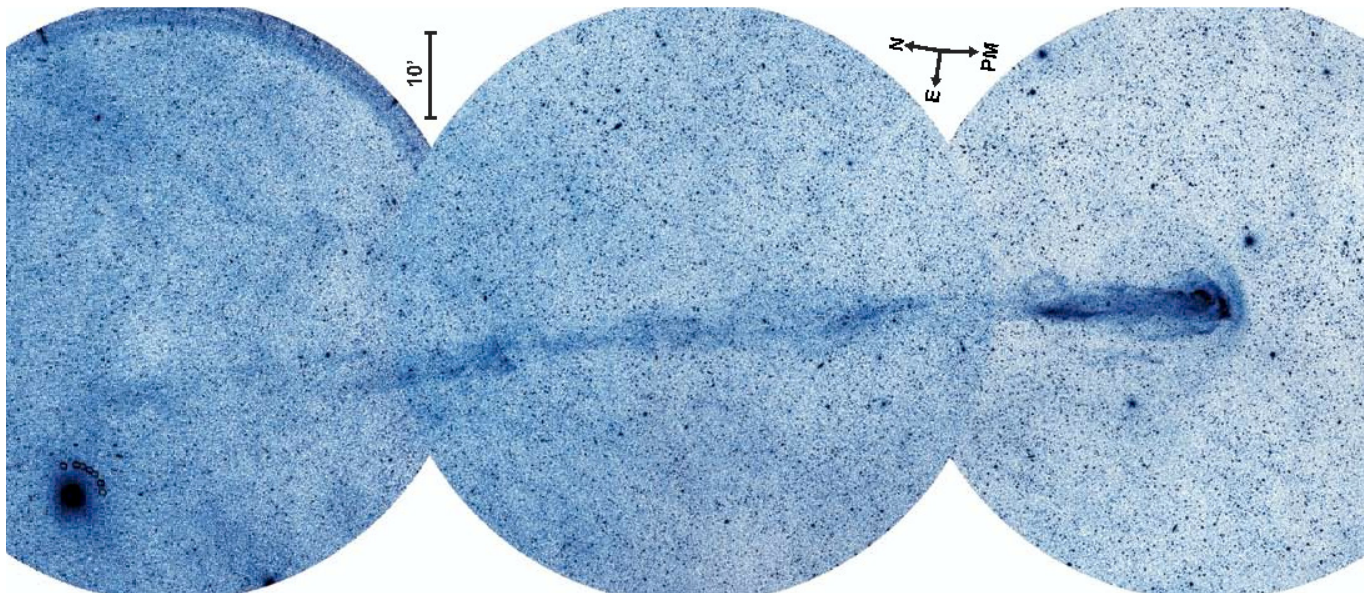


- These objects do not look like PNe
- Structure is highly dependent on the AGB structure of the tail
- IPHAS may have uncovered several objects like this
(as we heard in Laurence's talk)

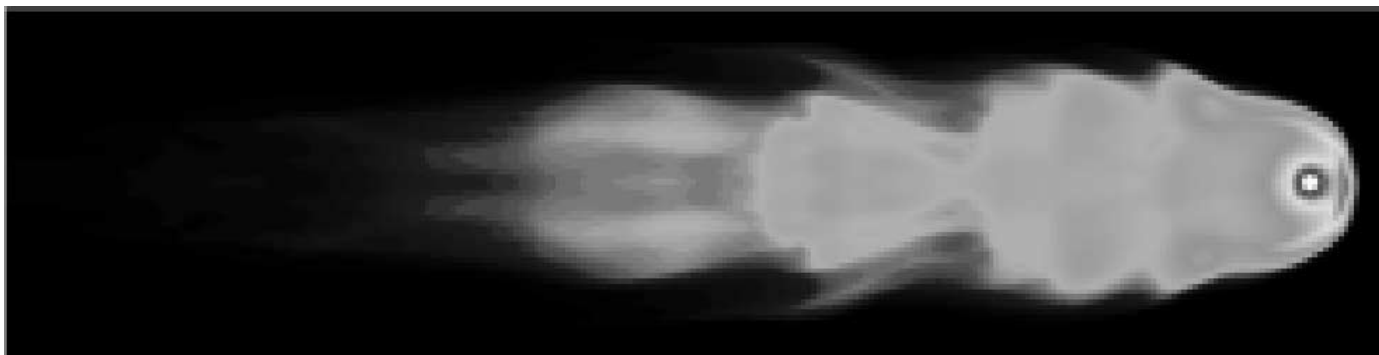




Here's one made earlier...



GALEX UV image mosaic of a tail behind Mira





Recent simulations

- Previously did ~ 100 3D hydrodynamical simulations employing a fully tested parallel CFD scheme which includes the effect of radiative cooling
 - mass-loss rate on the AGB: 10^{-7} , 5×10^{-7} , 10^{-6} , $5 \times 10^{-6} M_{\odot} \text{ yr}^{-1}$
 - local ISM density: $n_{\text{H}} = 2, 0.1, 0.01 \text{ cm}^{-3}$
 - relative velocities: 0 to 200 km s^{-1} in 25 km s^{-1} steps
- recent introduction of asymmetric mass-loss and a Helium flash-like mass-loss variation, characterised by:
 - beta; equator to pole mass-loss ratio
 - eta; controls steepness of drop off from equator
 - mass-loss variation:-
 - 1000 years at $3 \times \dot{M}$
 - 10,000 years at $\dot{M} / 3$
 - 100,000 years at \dot{M} & *repeat!*

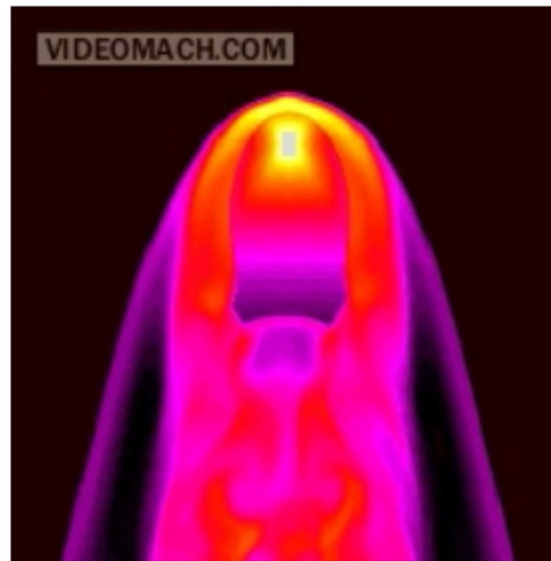




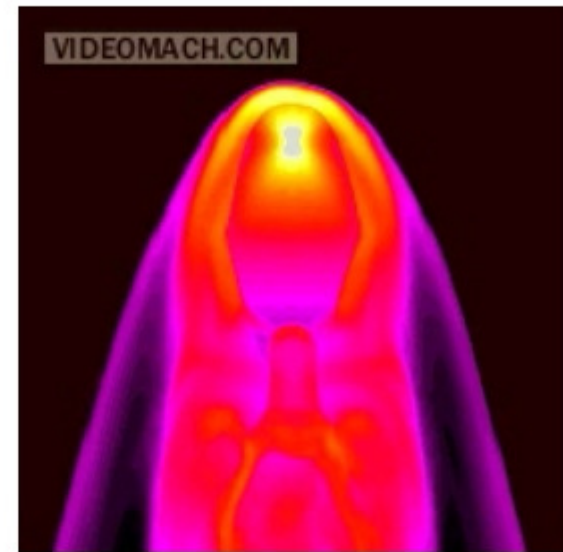
Asymmetry + Helium flashes



Beta = 0.5 (2:1), eta = 1



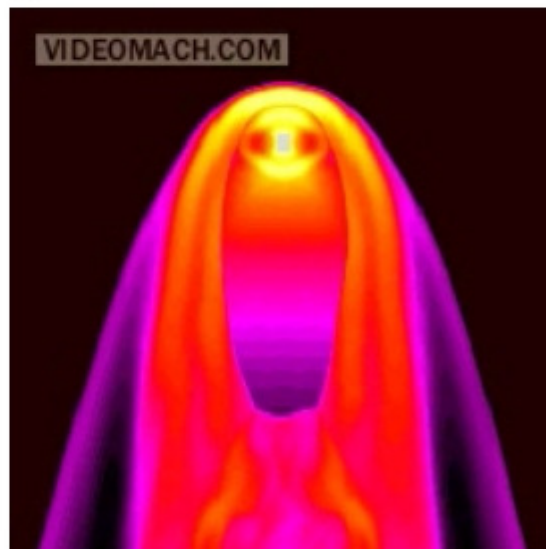
Beta = 0.8 (5:1), eta = 1



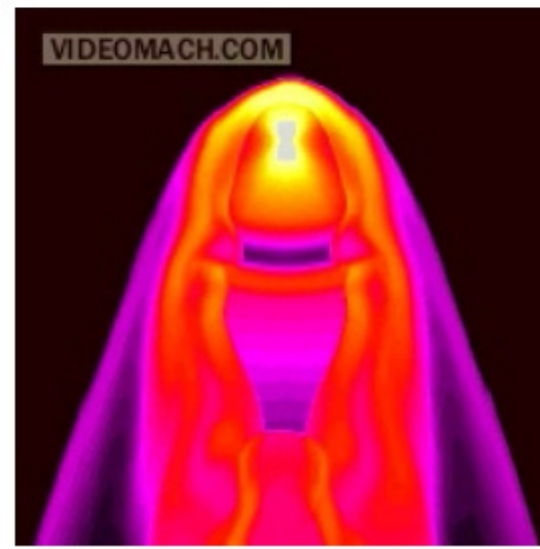
Beta = 0.9 (10:1), eta = 1

$3 \times 10^{-7} M_{\odot}/\text{yr}$
 $= 0.03 \text{ cm}^{-3}$
 $v = 5 \text{ km/s}$

$= 100 \text{ km/s}$



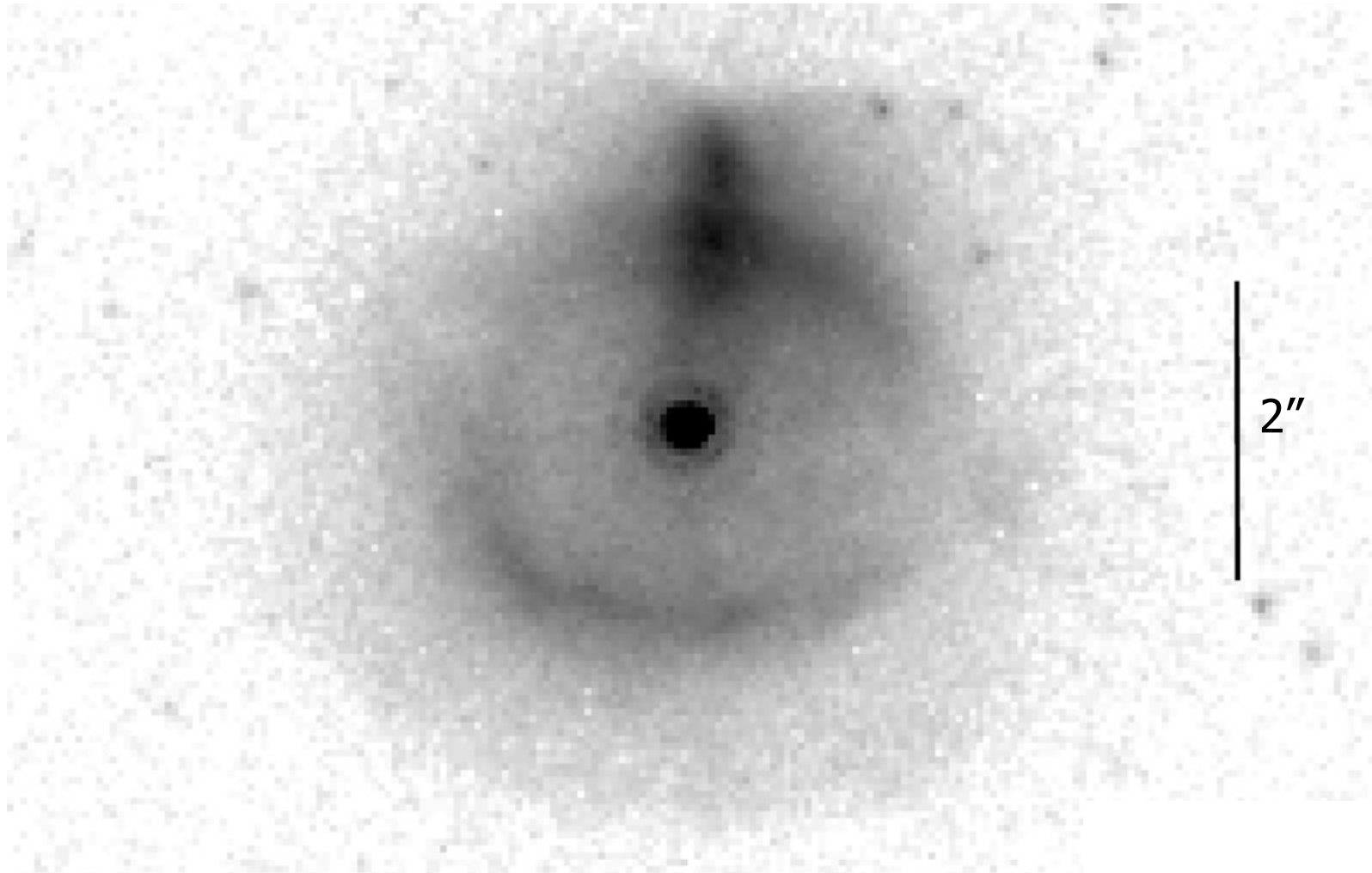
Beta = 0.9 (10:1) eta = 2



Beta = 0.95 (20:1) eta = 1



Galactic bulge PN M2-29





Implications

How does ISM interaction affect the death of a PN?

- AGB-ISM wall can rejuvenate/rebrighten an old PN
- movement through the ISM changes wall into a bow shock
- PN experiences one-sided rebrightening
- central star can leave its PN
- with high speed relative to the ISM, a PN can be completely disrupted





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Sh 2-188 - MNRAS **366** 387 (2006)

R Hya - MNRAS **372** L63 (2006)

Vortices in the wakes of AGB stars - ApJ **660** L129 (2007)

PN-ISM interaction - MNRAS **382** 1233 (2007)

Mira tail - ApJ **670** L125 (2007)



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