The University of Manchester
Jodrell Bank
Observatory

Mira
It's a wonderful prospect

or 'Revealing the mass-loss history of a star through AGB & PN – ISM interaction'

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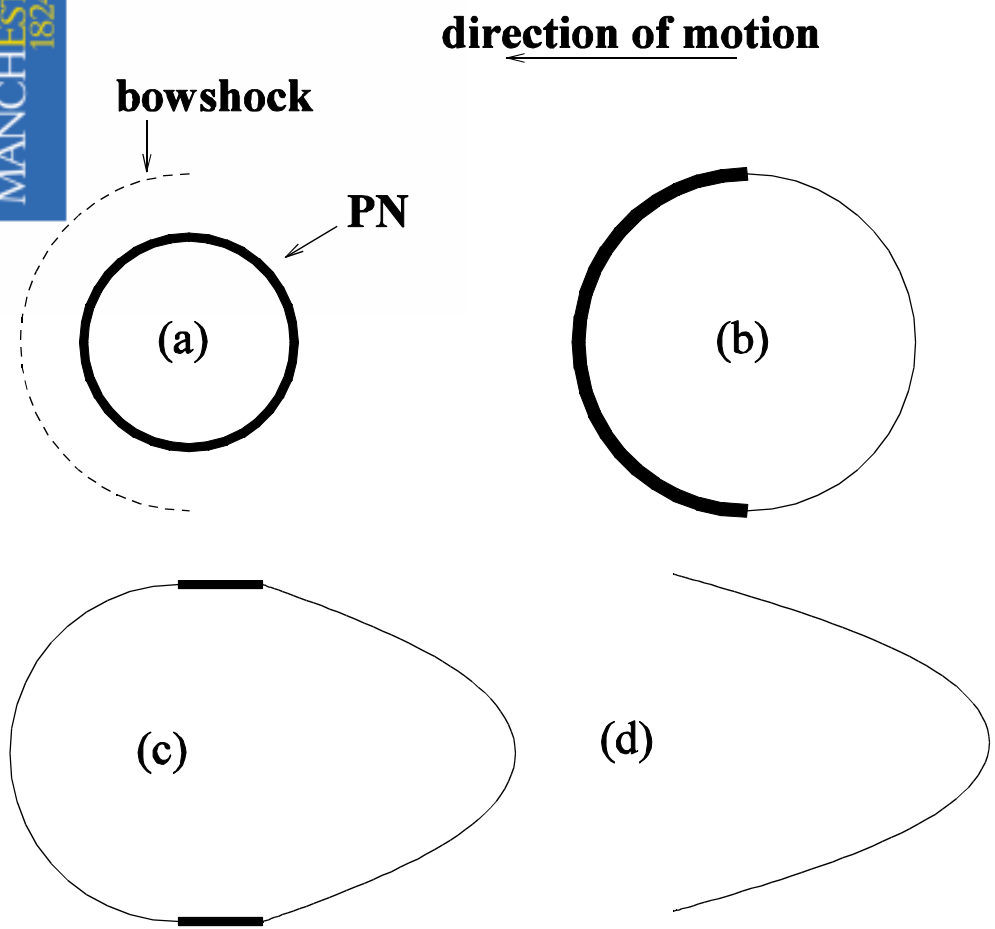
Jodrell Bank
22nd June 2010 – APN5

Generalisation of PN-ISM interaction



Stage WZO 1 - (a)

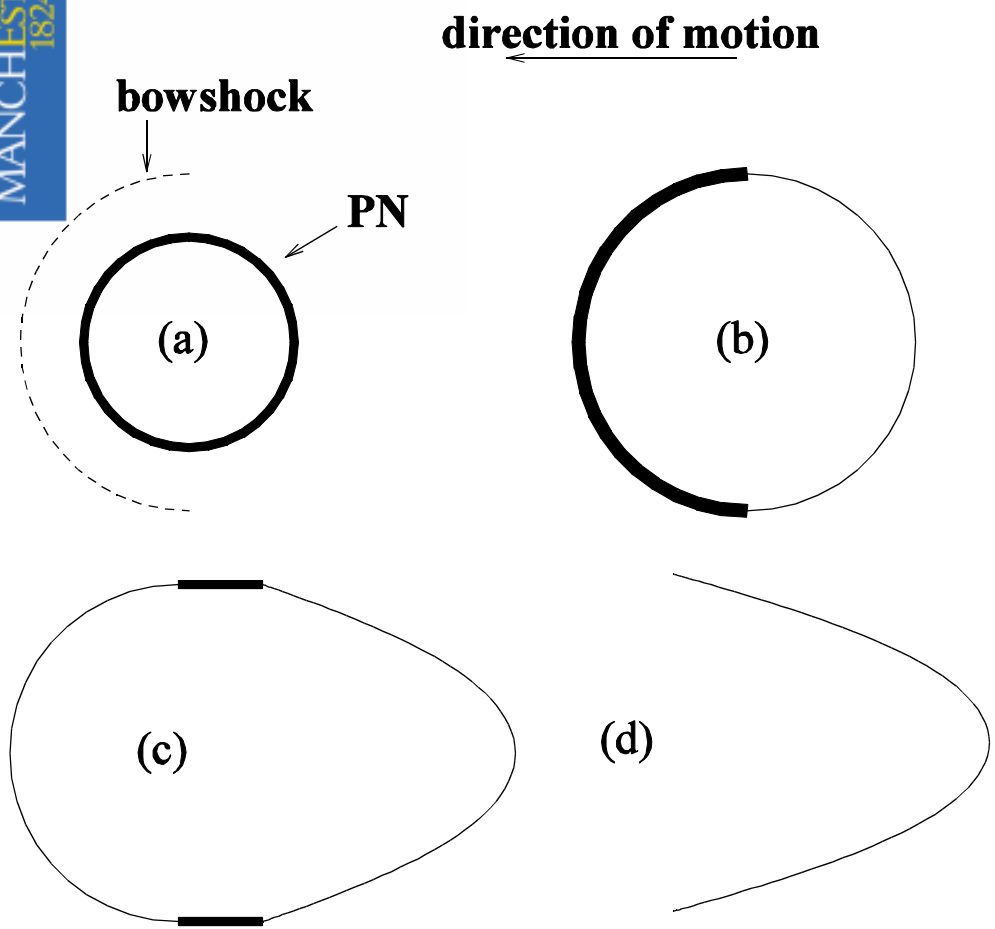
- PN as yet unaffected by the interaction but a faint bow shock may be observable

- In the case of a slow moving star or *low-density environment*, this may last for the lifetime of the PN.

- At even average velocities, interaction can become rapidly apparent.

Modelling of the AGB phase of evolution is crucial (Villaver 2003)

Generalisation of the interaction



Stage WZO 2 – (b)

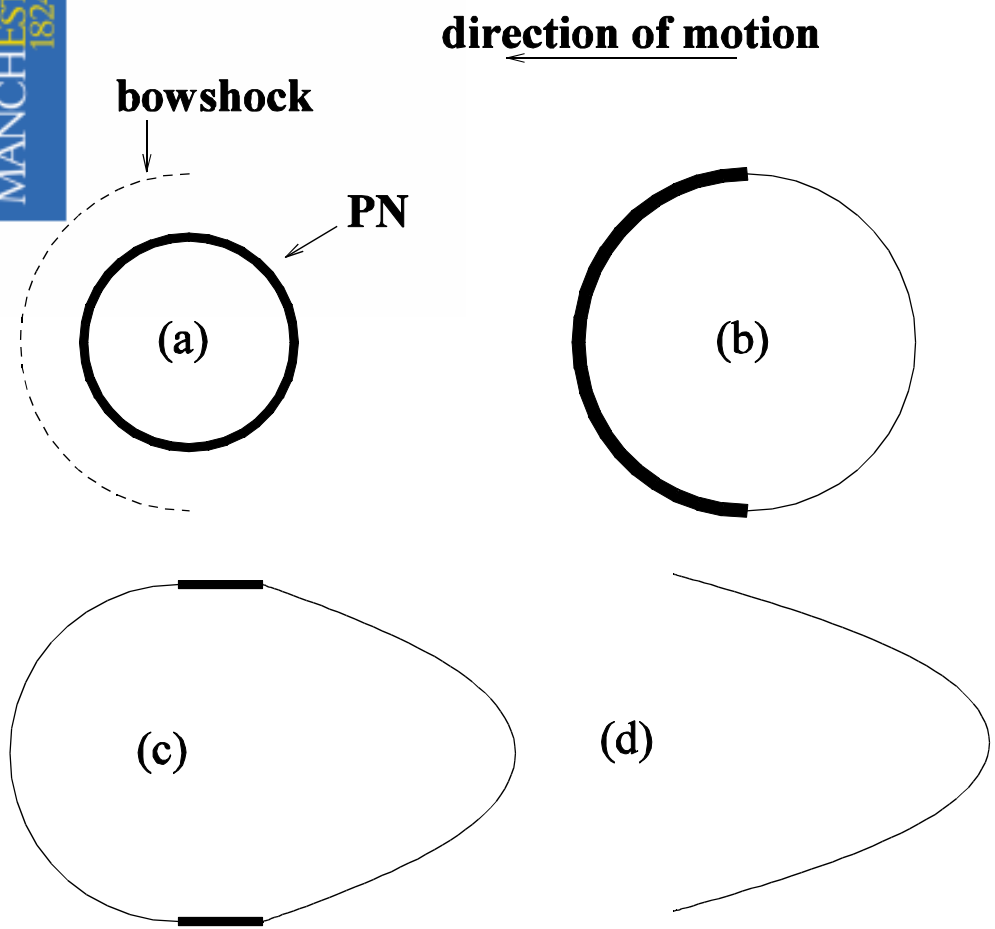
- PN has expanded far enough to interact with the bow shock.

- Density and temperature increase in region of interacting shocks

- As a consequence, nebular shell is brightened in the direction of motion: rebrightening

- Easily identified if motion is in the plane of the sky.

Generalisation of the interaction

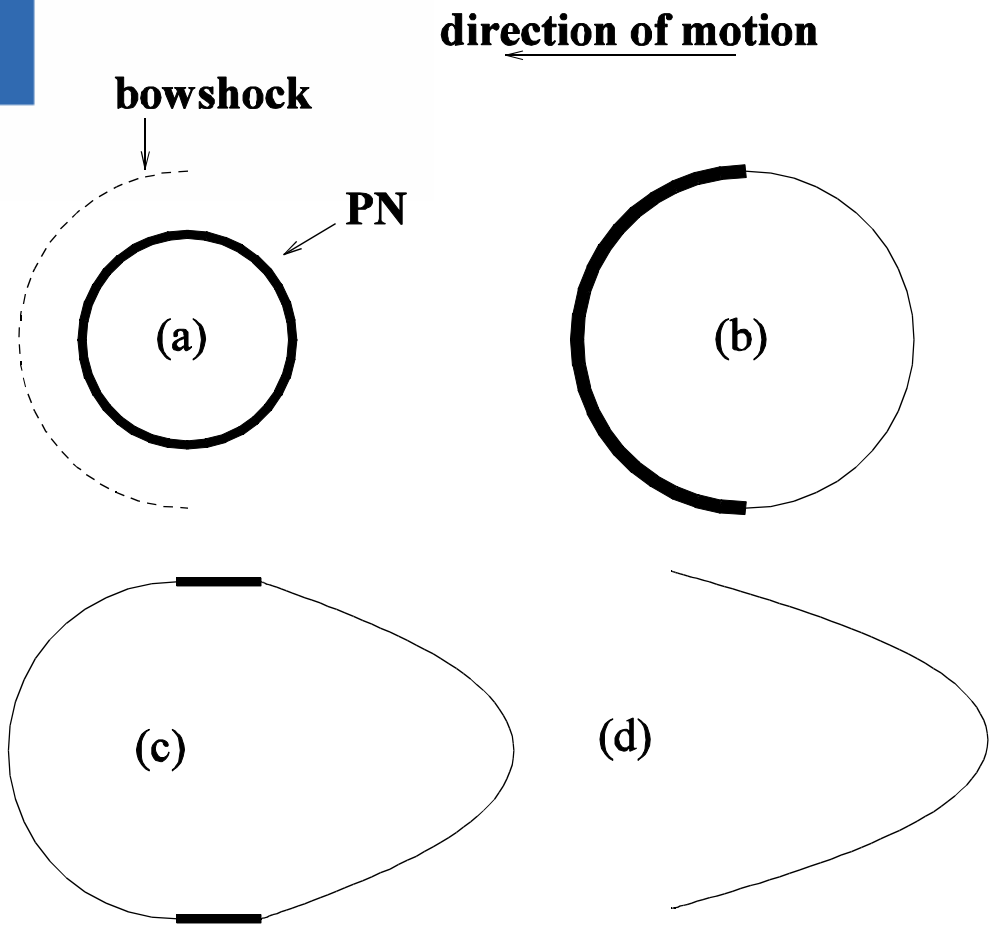


Stage WZO 3 – (c)

- the geometric centre of the nebula shifts downstream away from the central star.
- Provides a directly measurable effect of the interaction.
- Dynamical methods will provide underestimates of PN age.
- Highest density regions move downstream.
- Extreme case: Sh 2-68 where the star has left its nebula

Generalisation of the interaction

MNRAS, 382, 1233-1245 (2007)



Stage WZO 4 – (d)

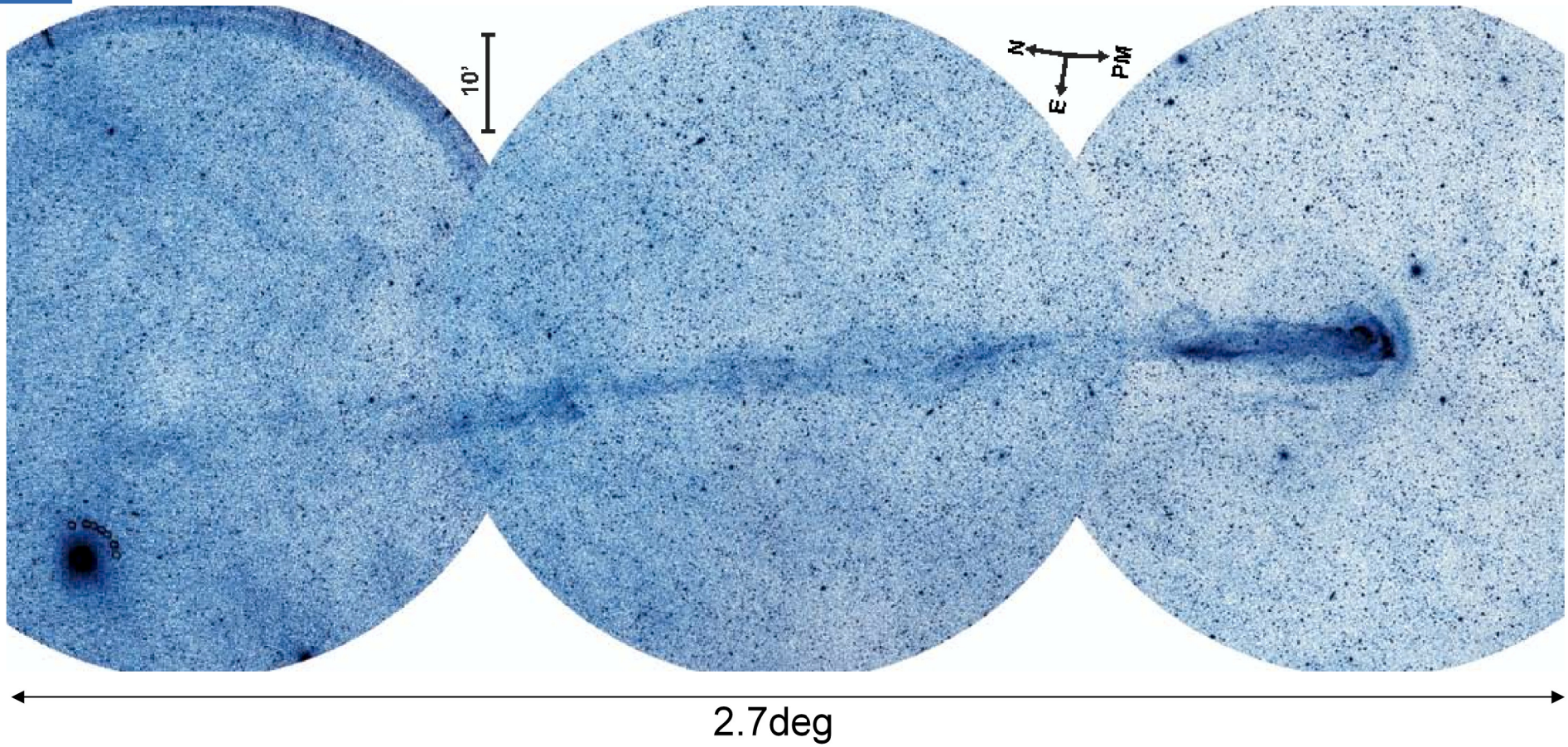
- fast wind has formed a bow shock ahead of the star.

- PN is completely disrupted; central star can now appear outside its nebula.

- Surveys may uncover many objects like this which would not be classed as PN.

Mira: Ultra-violet GALEX observation

- 31 observations, exposures 8,900, 11,200 & 11,500 s

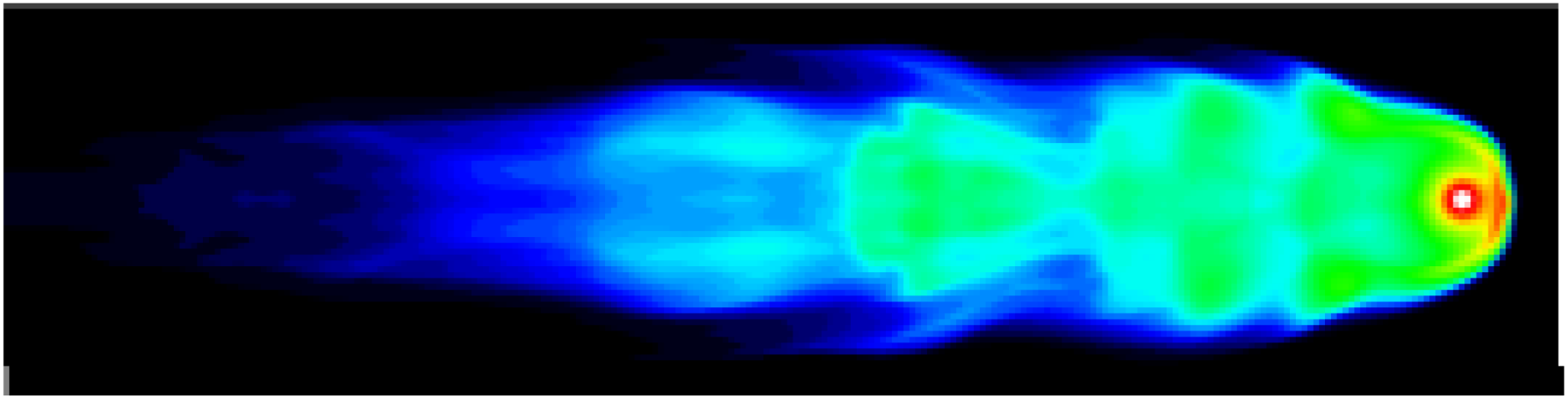


Mass loss history of Mira

- Martin et al concluded:-
  - bow shock and ram-pressure-stripped tail of material.
  - in agreement with the proper motion of the system.
  - spatial extent: 4pc => 30,000 years of mass-loss history.
  - density variations along the tail are the result of mass-loss variations.

Simulations

- Model:-
  - $dM/dt = 3\times10^{-7}\ M_{\odot}/yr$, $v_{wind} = 5$ km/s (based on CO line observations), space velocity = 130 km/s.
  - constant mass-loss rate
  - distance to bow shock: 0.1 pc implies a local ISM density $n_H = 0.03\ cm^{-3}$

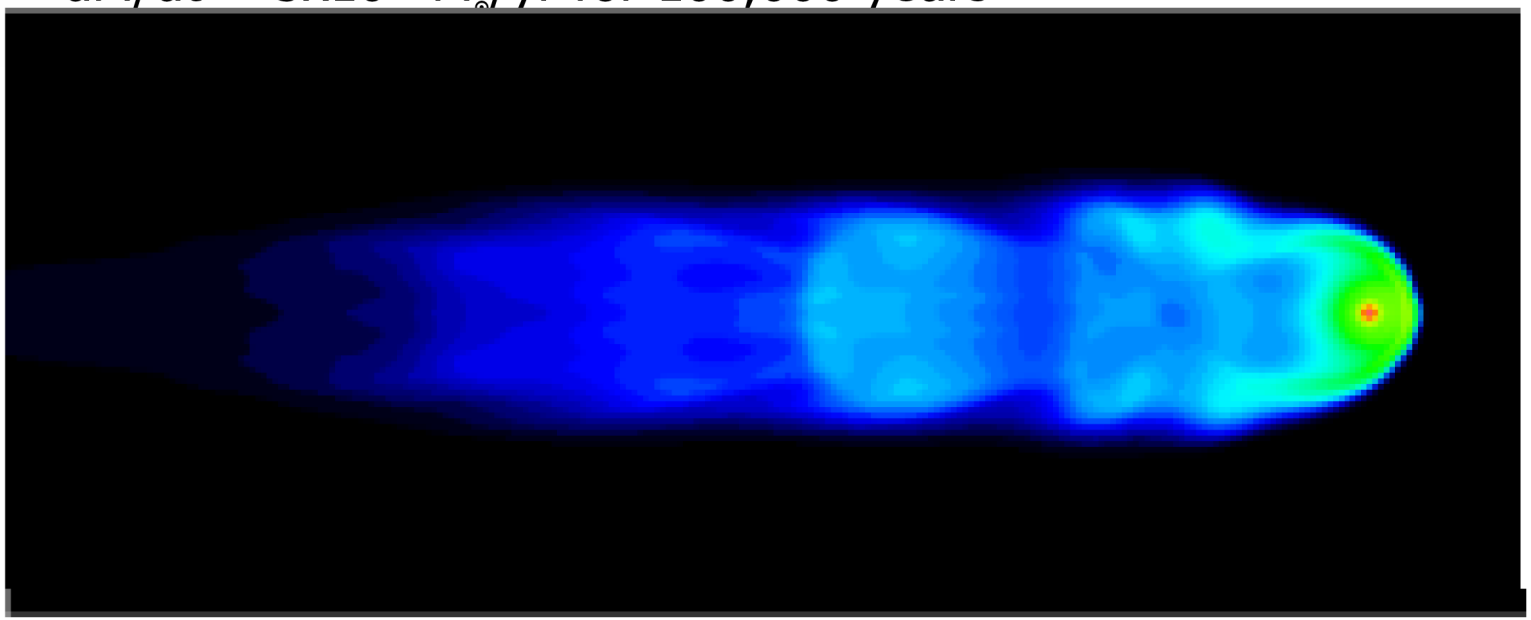


5pc x 1.25pc

450,000 years to form a 4pc tail!

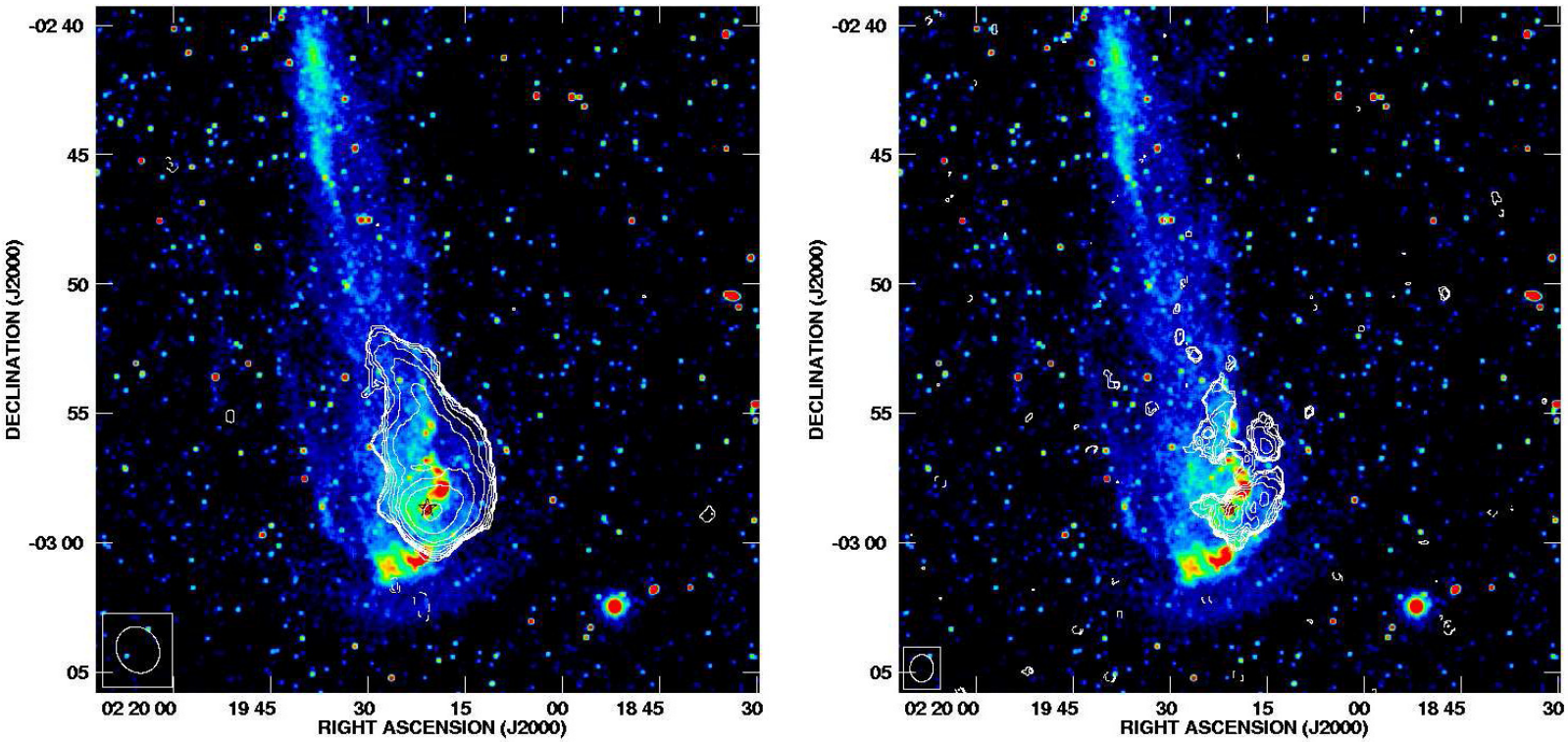
- Rerun simulation with varying mass-loss rate to represent Helium flashes.
  - dM/dt = 9×10^{-7} $M_\odot$/yr for 1000 years
  - dM/dt = 1×10^{-7} $M_\odot$/yr for 10,000 years
  - dM/dt = 3×10^{-7} $M_\odot$/yr for 100,000 years

pc x 2pc



Mass-loss variations are not immediately clear in the tail

Radio observations

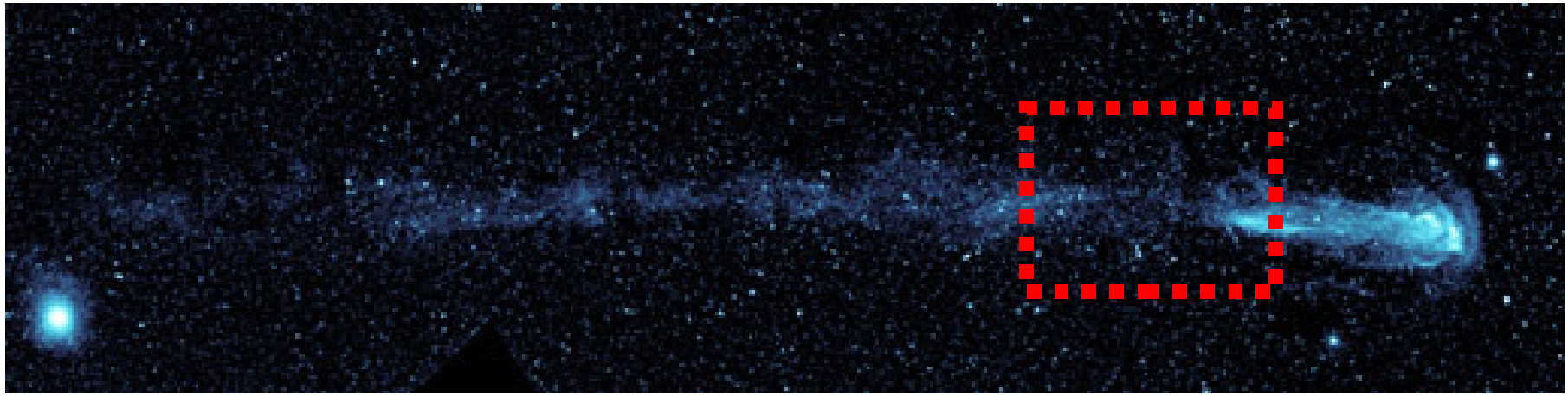


- H1 emission (VLA observation) overlaid on GALEX observation.

Radio mapping with Nancay Radio Telescope reveals a clear slowing-down of the material in the tail with increasing distance from Mira.

Matthews et al. ApJ **684** 603 (2008)

Gaps in the tail?



Why is there a recent gap in the tail?

- High density to low density environment change; entering the local bubble?
- Ueta et al estimated the cometary astropause to be around 40,000 years old (ApJ **687** L33 (2008)).
- Agrees with our theoretical prediction of the shock reestablishment time after Mira entered the local bubble.

See poster by Esquivel et al

- Galactic Orbit modelling:-
  - $dM/dt = 3x10^{-7}\ M_{\odot}/yr$
  - $v_{wind} = 5$ km/s
  - space velocity = 130 km/s
  - constant mass-loss rate
  - $n_H = 0.75\ cm^{-3}$ for 200,000yrs
  - ISM vector changes by 30deg over this time

The End.

Re-examination in AMR k-epsilon turbulence code

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