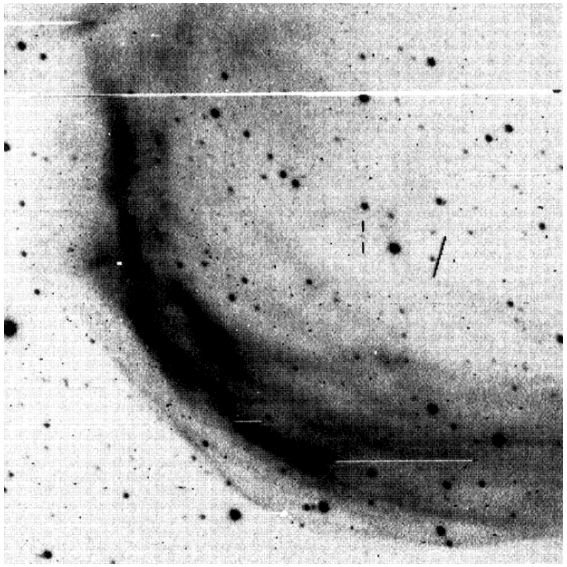
The bow shock and wind-ISM interaction of a speedy PN



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Overview

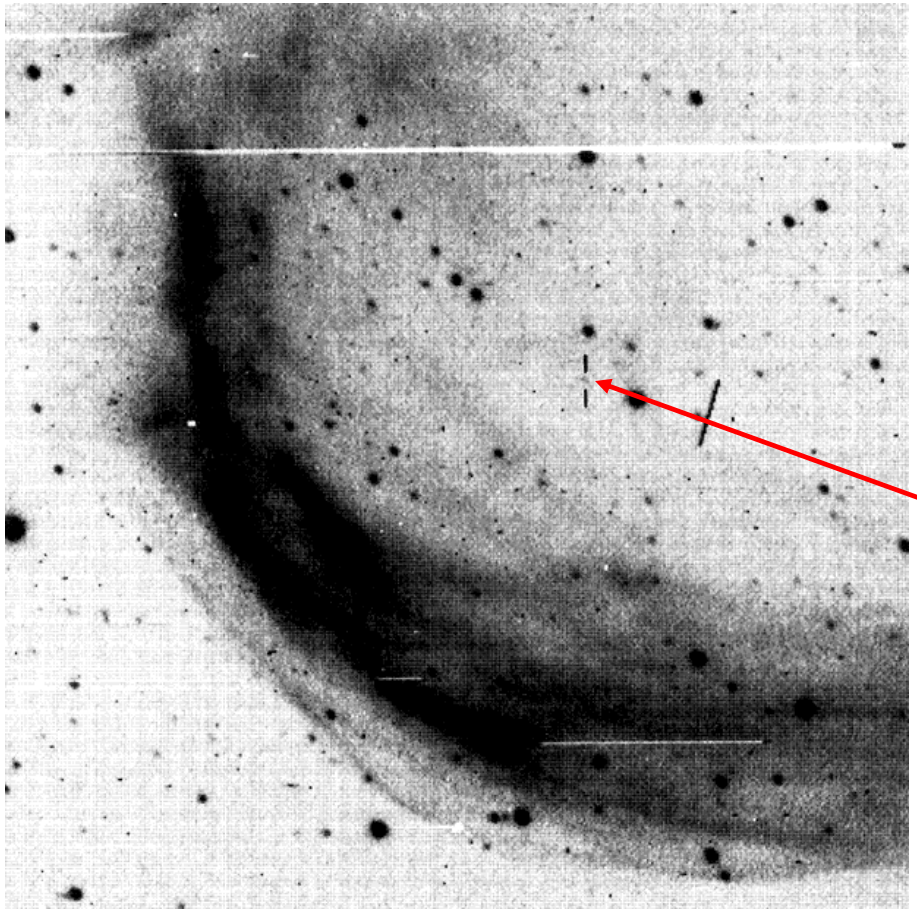
- Observations, from 1970s to date.
- Suggested model and properties of the object.
- Numerical simulations of the system.
- Current project status.

Sh2-188: Vital Statistics

- Galactic Plane PN
- Interaction with ISM suggests highly evolved object
- Bright filaments suggest an highly inhomogeneous ISM in the vicinity.
- Distance unclear:
  - D = 600pc, r = 0.5pc, t = 12,100yr
  - D = 220pc, r = 0.18pc, t = 4400yr *
  - D = 965pc, r = 0.88pc, t = 22000yr

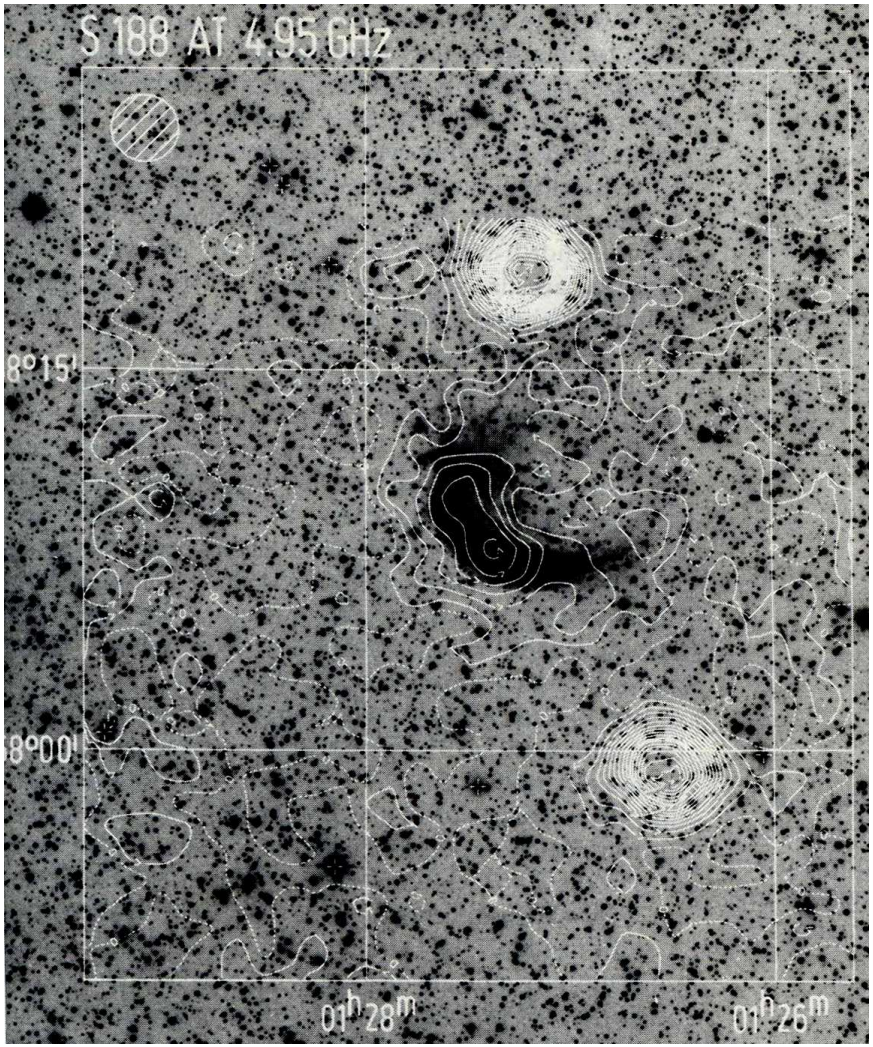
* Shklovski distance: likely to be underestimating PN mass and thus distance

Sh2-188: Optical observation



- Southeast region. 3600s Hα exposure. The image is 5.7’ on a side with North up and East to the left.
- Central star candidate
- Kwitter, Jacoby and Lydon, AJ, (1988), 96, 997.

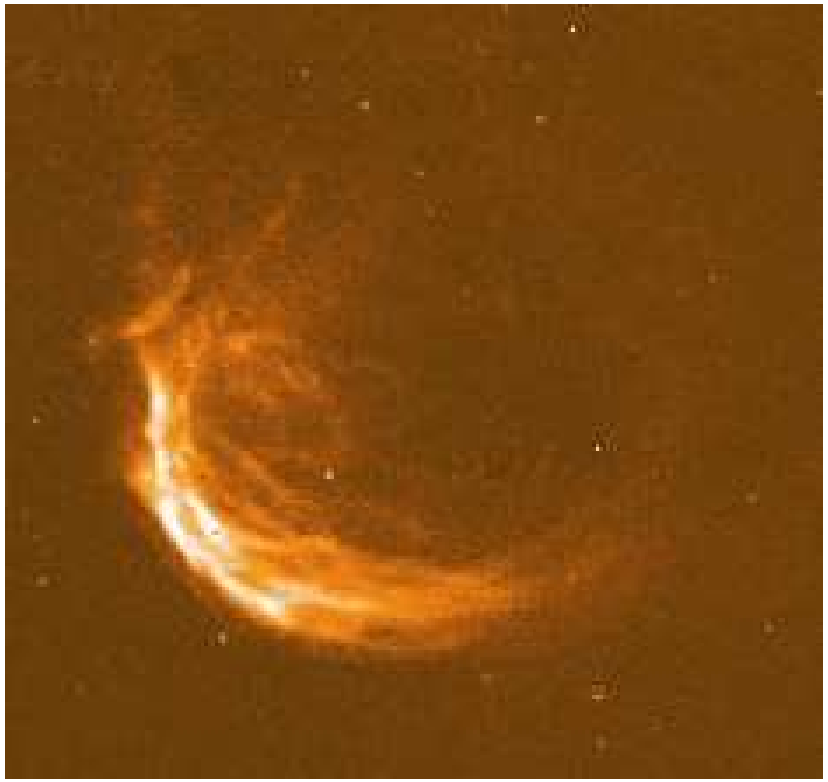
Sh2-188: Radio observation



- Total intensity contour map at 5 GHz superimposed on the Palomar Sky Survey red print of the field. Peak flux at 140 ± 17 mJy.

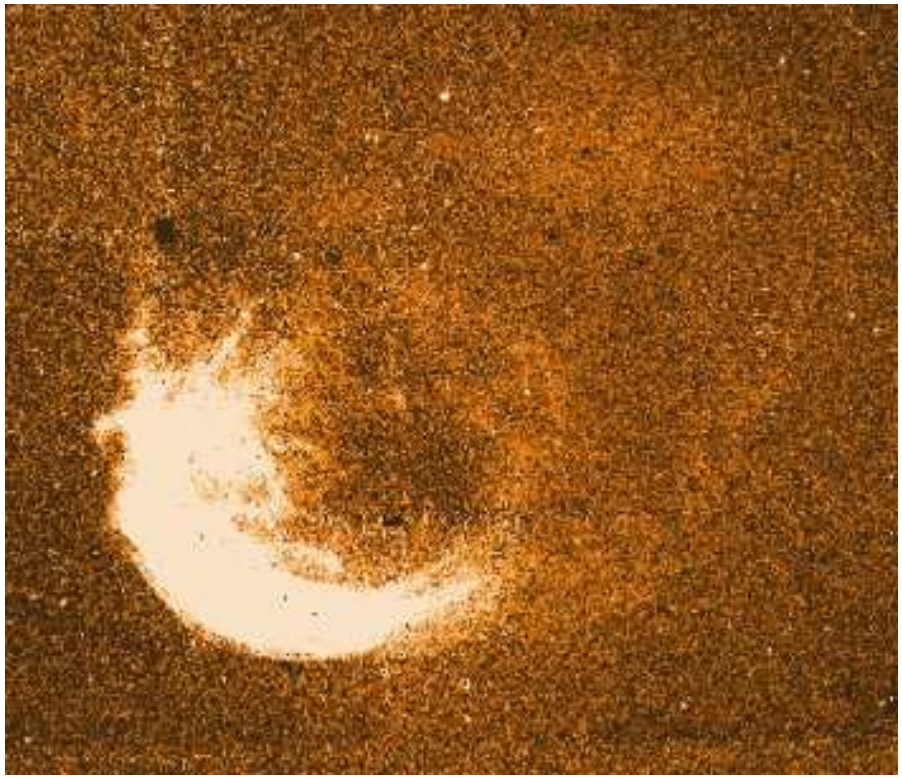
- Salter et al., A&A, 131, 291, (1984).

Sh2-188: Current observation



- Hα image from INT Photometric Hα survey (IPHAS).
- Note the filamentary structure.
- Drew et al. in prep.

Sh2-188: Current observation



- Deep Hα image from INT Photometric Hα survey (IPHAS).

- Drew et al. in prep.

Form of Sh2-188

- Large-scale nebula suggests this is an old PN
- Brightening in the South-East suggests this PN is in fact moving through the ISM
- Fragmentation of the bow-shock causing filamentary appearance
  - Due to Rayleigh-Taylor instabilities.
  - Galactic magnetic fields may be playing an important part.
- Theoretically, fragmentation occurs with a relative ISM velocity of 100 km/s

Dgani and Soker, ApJ, 434, 262 (1994); Dgani and Soker, ApJL, 499, L83, (1998)

Numerical Simulations

- We are aiming to progressively develop a model of PN-ISM interaction by modelling the following:
  - Symmetric slow AGB wind originating from a source moving through the ISM.
  - Symmetric fast post-AGB wind from the same source sweeping up the slow AGB wind, so as to investigate the shaping effect of movement through the ambient medium.
- Various speeds through the ISM – 25, 50, 75, 100, 125, 150 & 175 km/s

Hydrodynamic Code

- 3-dimensional.
- Fully parallel, developed over the last three years.
- Cartesian co-ordinates.
- 2nd order, Godunov-type Eulerian code.
- Grid size up to 700 x 700 x 700.
- Fully tested and memory efficient.
- Radiative cooling effects included

- Simulations performed on COBRA, a Beowulf cluster at Jodrell Bank consisting of 192 1Ghz processors and a total of 67.5 Gb of memory.

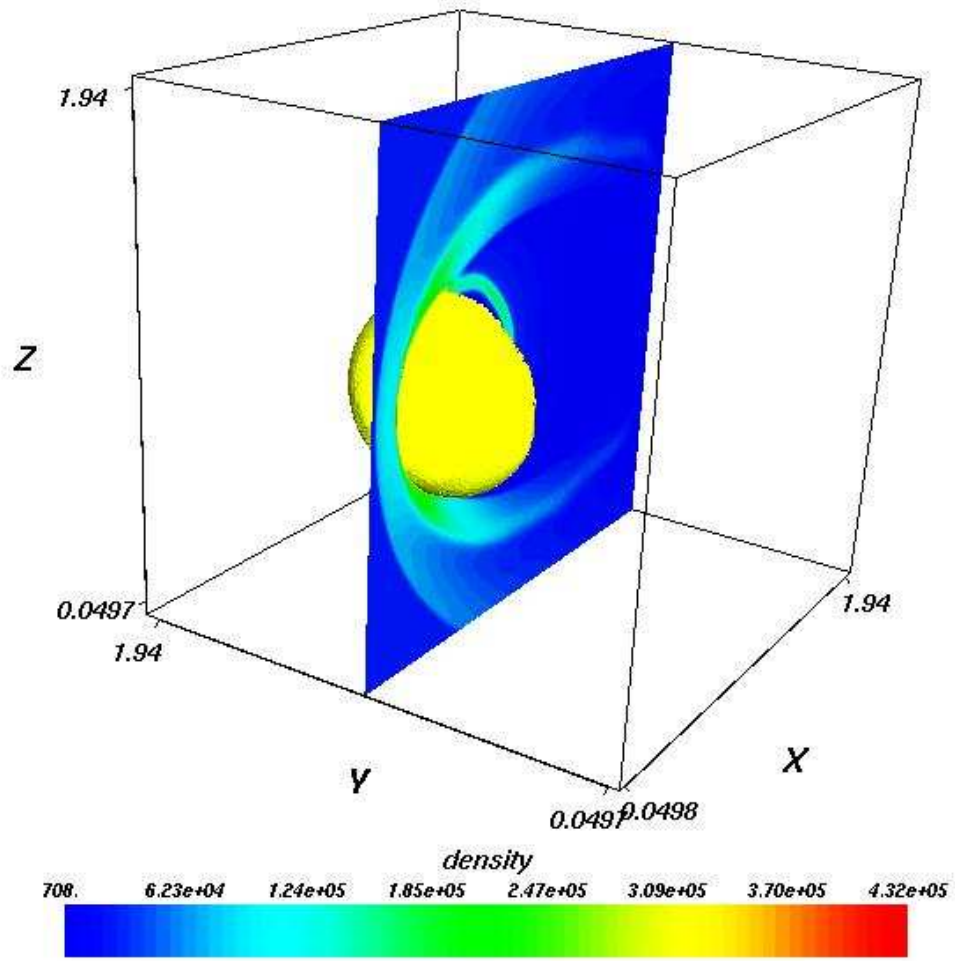
Current status

- $\log_{10}$ density slice of a cubic grid 2pc on each side, 200^3 resolution
- slow AGB wind ($1x10^5$ yrs)
  - dM/dt = $1x10^{-6}$ $M_\odot$ /yr
  - v = 15 km/s
  - T = 10,000 K
- fast post-AGB wind ($2x10^4$ yrs)
  - dM/dt = $5x10^{-8}$ $M_\odot$ /yr
  - v = 1000 km/s
  - T = 50,000 K

- v_{ISM} = 25 km/s

24 hours on 10 processors of COBRA

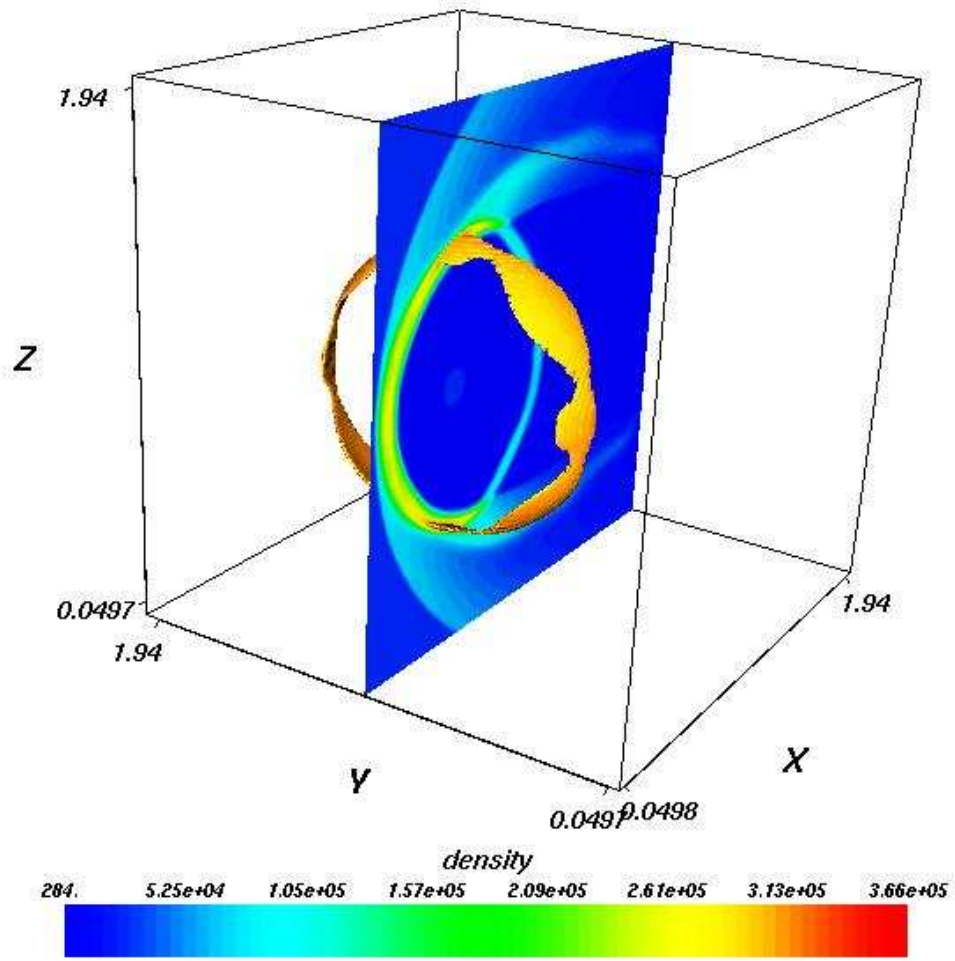
Current status



- Grid is 2pc on a side

- Density slice and high-density iso-surface suggesting the shape of the observed PN, 8000 years after the onset of the fast wind.

Current status



- Grid is 2pc on a side

- Density slice and high-density iso-surface suggesting the shape of the observed PN, 13000 years after the onset of the fast wind.

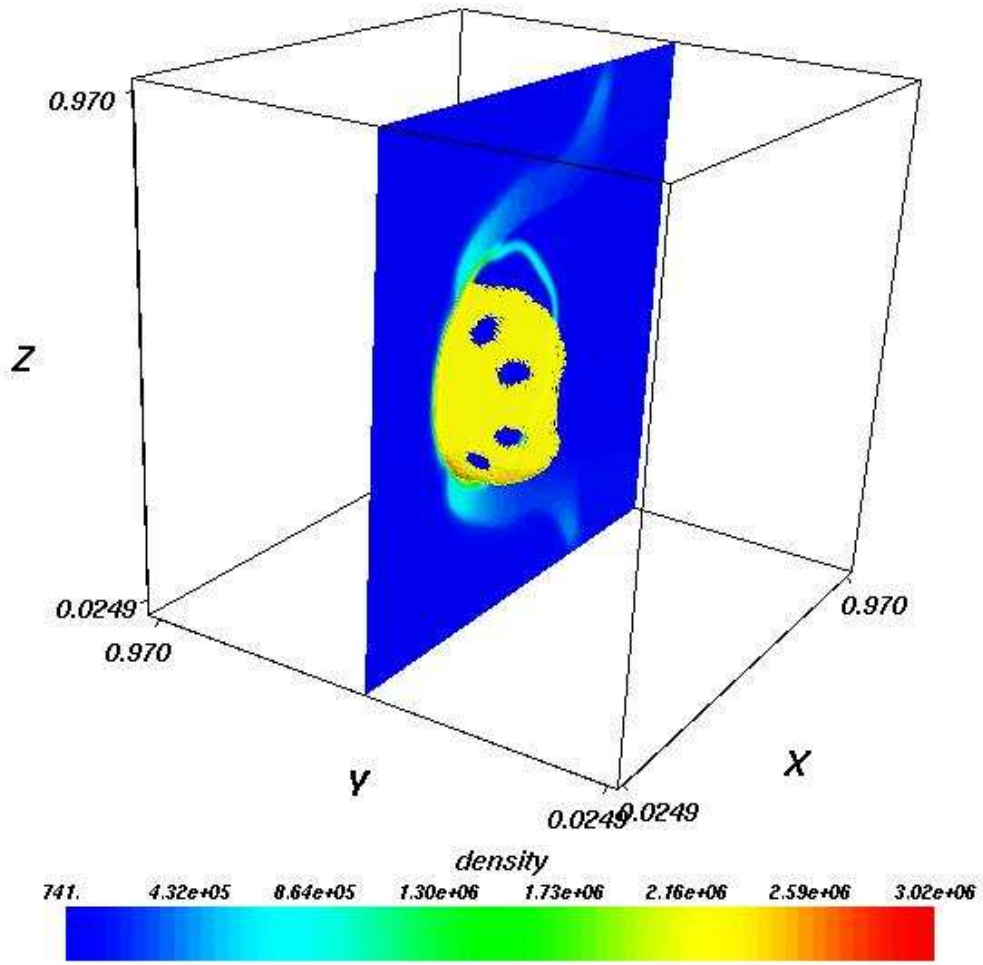
Current status

- $\log_{10}$ density slice of a cubic grid 1pc on each side, 200^3 resolution
- slow AGB wind ($1x10^5$ yrs)
  - dM/dt = $1x10^{-6}$ $M_\odot$ /yr
  - v = 15 km/s
  - T = 10,000 K
- fast post-AGB wind (10^4 yrs)
  - dM/dt = $5x10^{-8}$ $M_\odot$ /yr
  - v = 1000 km/s
  - T = 50,000 K

- v_{ISM} = 50 km/s

37 hours on 10 processors of COBRA

Current status



- Grid is 1pc on a side

- Density slice and high-density iso-surface suggesting the shape of the observed PN, 4000 years after the onset of the fast wind.

Current status

- $\log_{10}$ density slice of a cubic grid 1pc on each side, 200^3 resolution
- slow AGB wind ($1x10^5$ yrs)
  - dM/dt = $1x10^{-6}$ $M_\odot$ /yr
  - v = 15 km/s
  - T = 10,000 K
- fast post-AGB wind (10^4 yrs)
  - dM/dt = $5x10^{-8}$ $M_\odot$ /yr
  - v = 1000 km/s
  - T = 50,000 K

- v_{ISM} = 75 km/s

39 hours on 10 processors of COBRA

Current status

- $\log_{10}$ density slice of a cubic grid 1pc on each side, 200^3 resolution
- slow AGB wind ($1x10^5$ yrs)
  - dM/dt = $1x10^{-6}$ $M_\odot$ /yr
  - v = 15 km/s
  - T = 10,000 K
- fast post-AGB wind (10^4 yrs)
  - dM/dt = $5x10^{-8}$ $M_\odot$ /yr
  - v = 1000 km/s
  - T = 50,000 K

- v_{ISM} = 100 km/s

52 hours on 10 processors of COBRA

Implications

- As you may expect, a particular sequence of evolutionary phases seems common whilst varying speed of movement through ISM.

- The faster the movement, the quicker the PN evolves through these phases:
  1. Symmetric circular PN (inside reverse shock)
  2. Bow shock-PN interaction
  3. Fast wind bow shock. AGB material swept back downstream.

- The second phase resembles the appearance of Sh2-188. Speed through the ISM affects the age and size estimates of the PN.

- Not necessarily a old PN.

Future simulations

- Repeating various relative speeds at higher resolutions (x2) to investigate structures.
- Particularly high resolution (x8) in the region of the shell to investigate fragmentation of shell.
- Variation of AGB and post-AGB wind parameters to investigation shape of PN and fragmentation of shell.

The End!