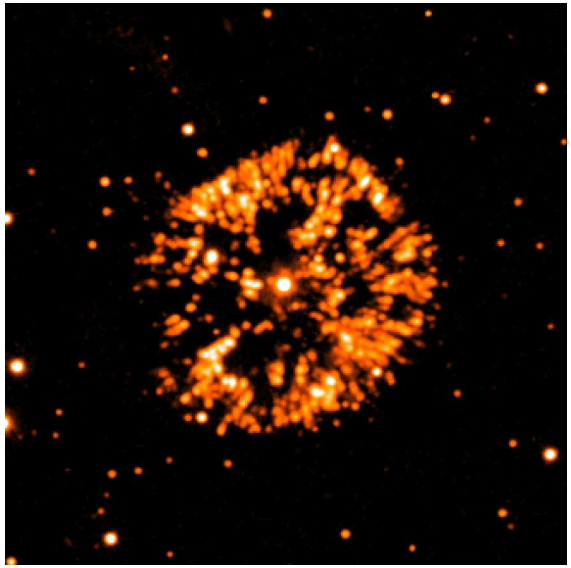
Nova GK Per and its surrounding ancient bipolar PN



Chris Wareing

7th September 2004

Jodrell Bank Observatory

Overview

- Observations, from 1901 to date.
- Suggested form of the surrounding ambient medium.
- Numerical simulations of the system.
- Current project status.

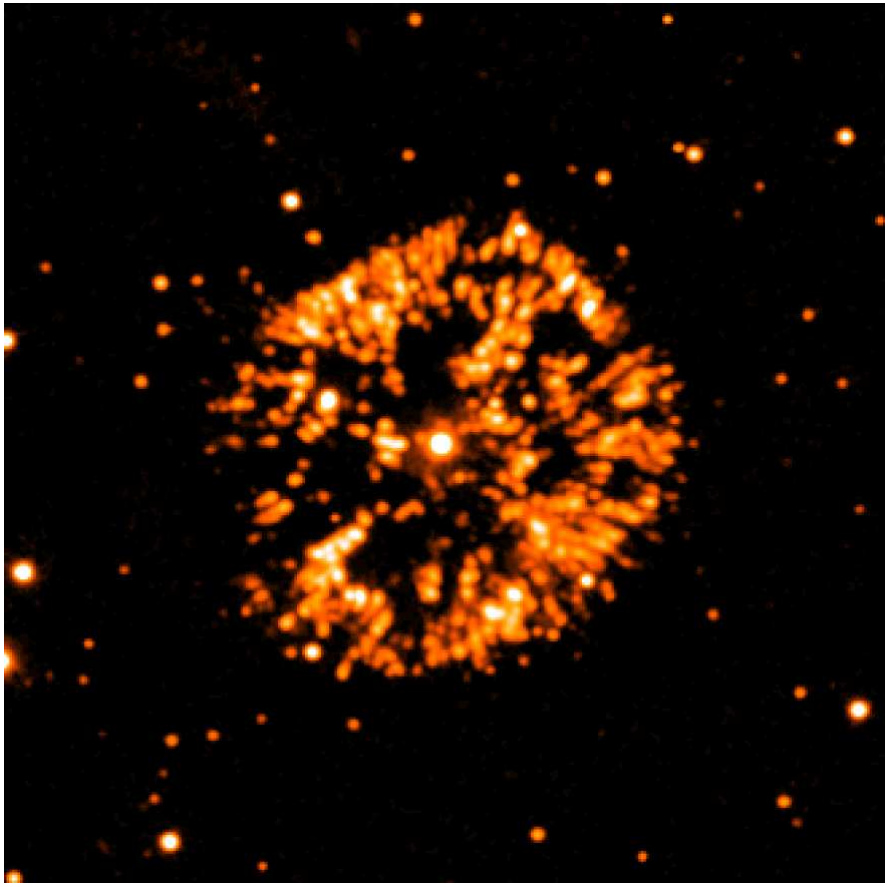
GK Per: Vital Statistics

- Very fast nova (Feb 22nd 1901).
- d = 470 pc (expansion parallax).
- $L_{max} \sim 5 \times 10^{38}$ ergs/s.
- $M_{ej} \sim 10^{-4}\ M_{sun}$, v_{ej} = 1200 km/s.

Central System:

- P = 1.904 d; WD (intermediate polar) + K2IV (evolved off MS; unusual for CN).
- Primary mass ~ 1 M_{sun}; Secondary mass ~ 0.2 M_{sun}.
- Dwarf nova outbursts.

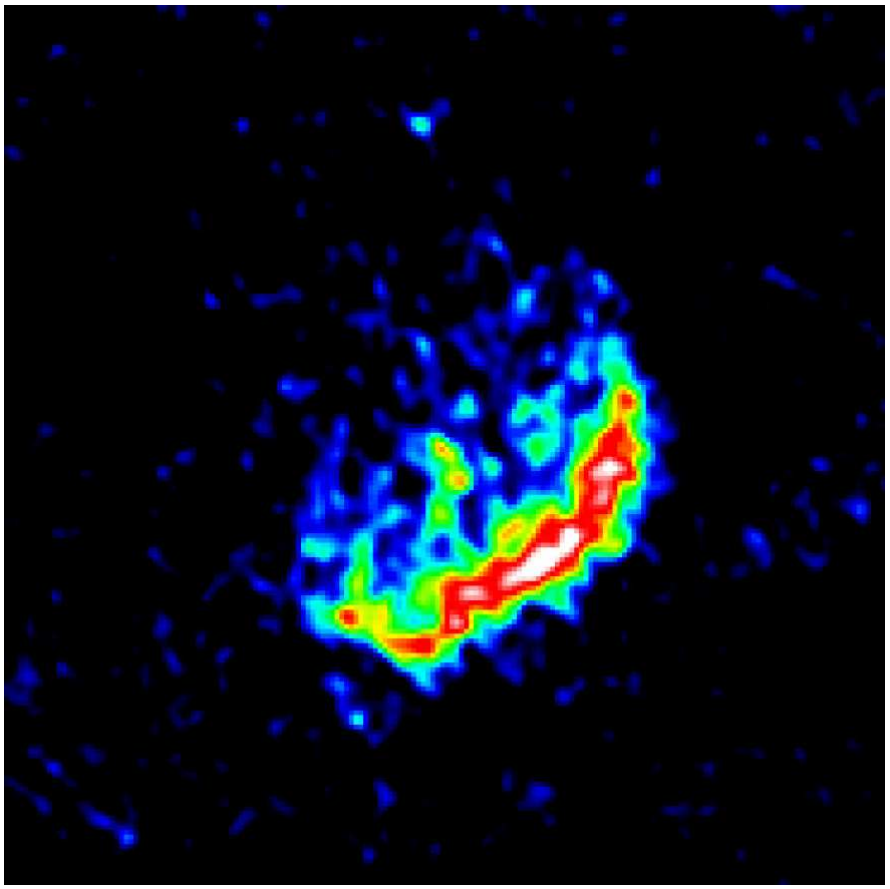
GK Per: Optical observation



- WHT Hα/[NII] image taken 1993 September (Slavin, O'Brien & Dunlop 1995).

- Image is 3' x 3' on a side, with North up and East to the left.

GK Per: Radio observation

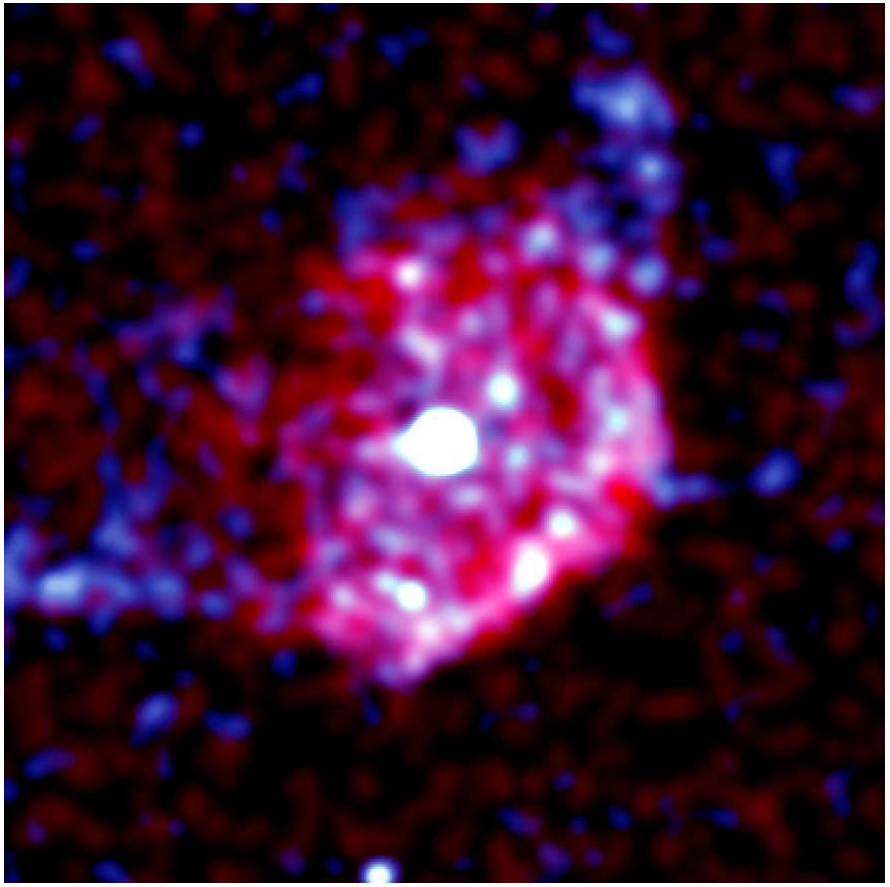


- 5 GHz radio image taken with the VLA in 1997 August.

- Regions of nonthermal (synchrotron) emission (Seaquist 2003, private communication).

- Image is 3′ x 3′ on a side, with North up and East to the left.

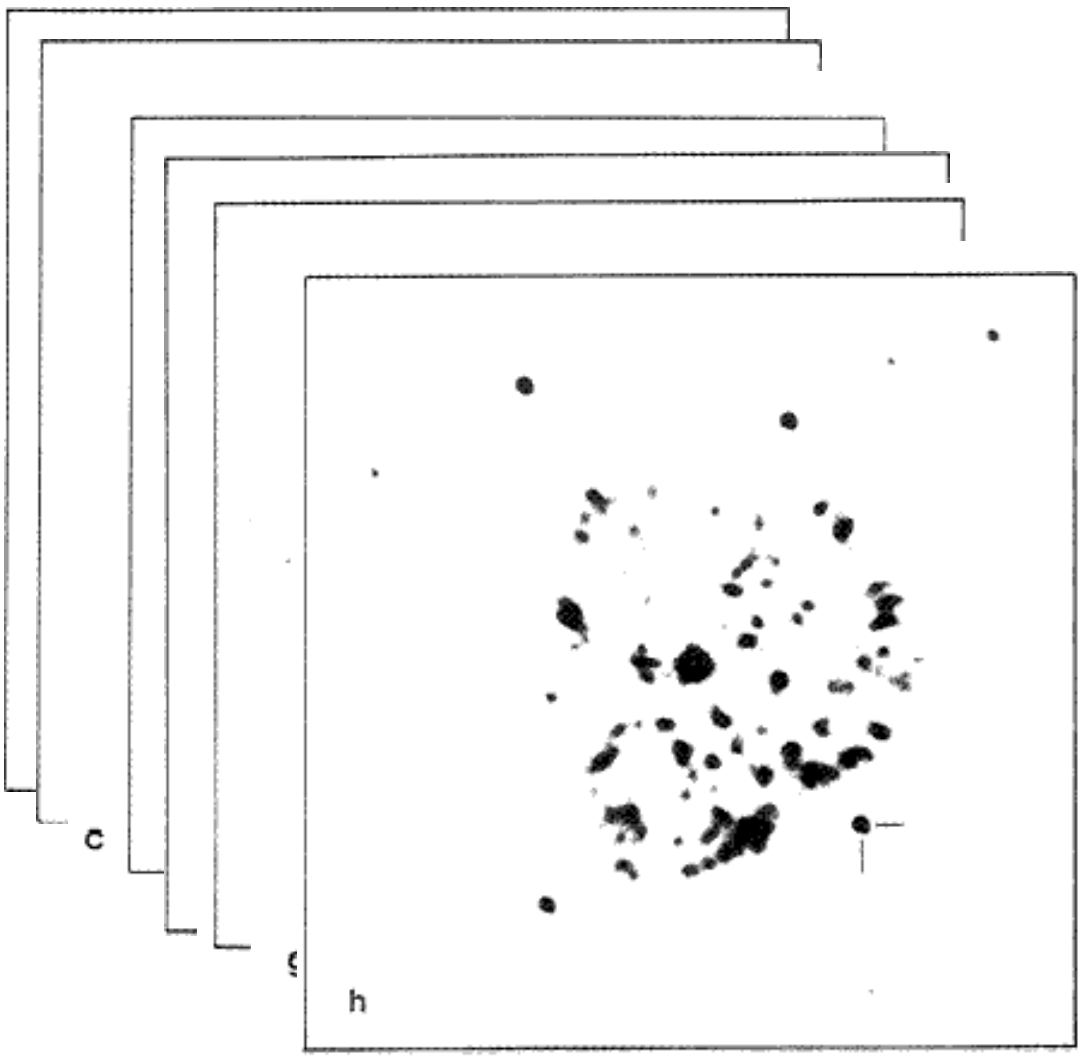
GK Per: Chandra observation



- Chandra image from 2000 February showing X-ray emission in the 0.4-0.6 keV (*red*) and 0.8-1.0 keV (*blue*) bands (Balman 2002).

- Image is 3′ x 3′ on a side, with North up and East to the left.

GK Per: Early observations

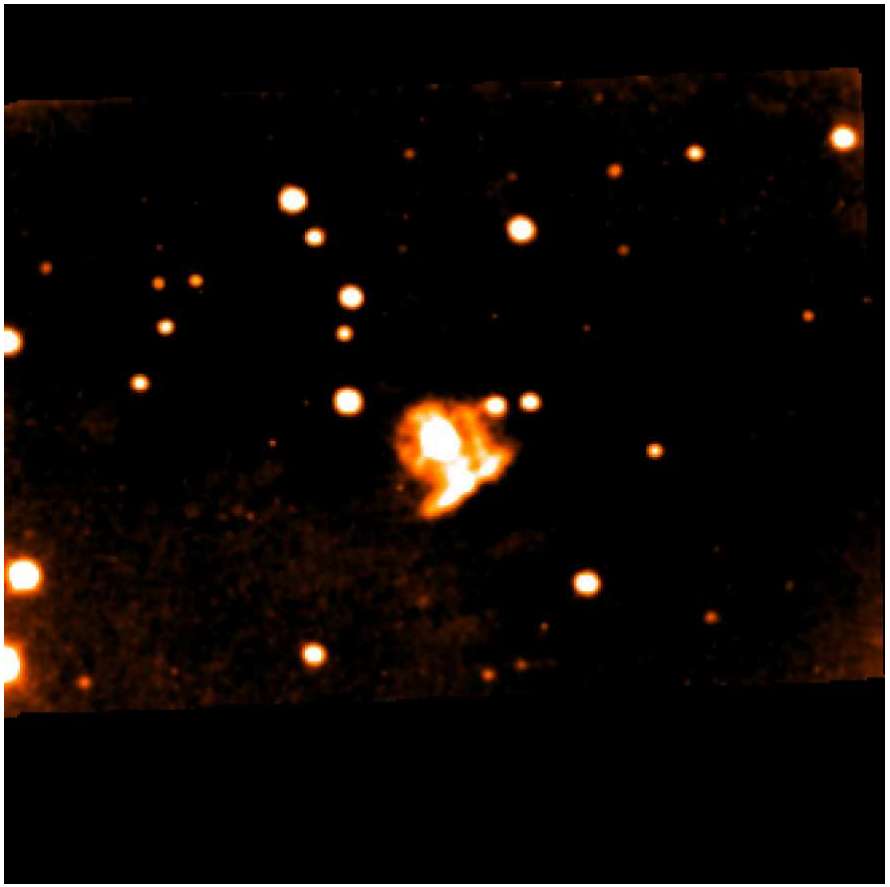


- Photographs of the expanding ejecta of GK Per (taken from Seaquist et al. 1989).

a) 1917 Nov. 5
b) 1937 Oct. 6
c) 1942 Nov. 6
d) 1944 Oct. 15
e) 1949 Nov. 20
f) 1959 Dec. 19
g) 1972 Sep. 8
h) 1977 Nov. 16

All images are 3′ x 3′ on a side, with North up and East to the left.

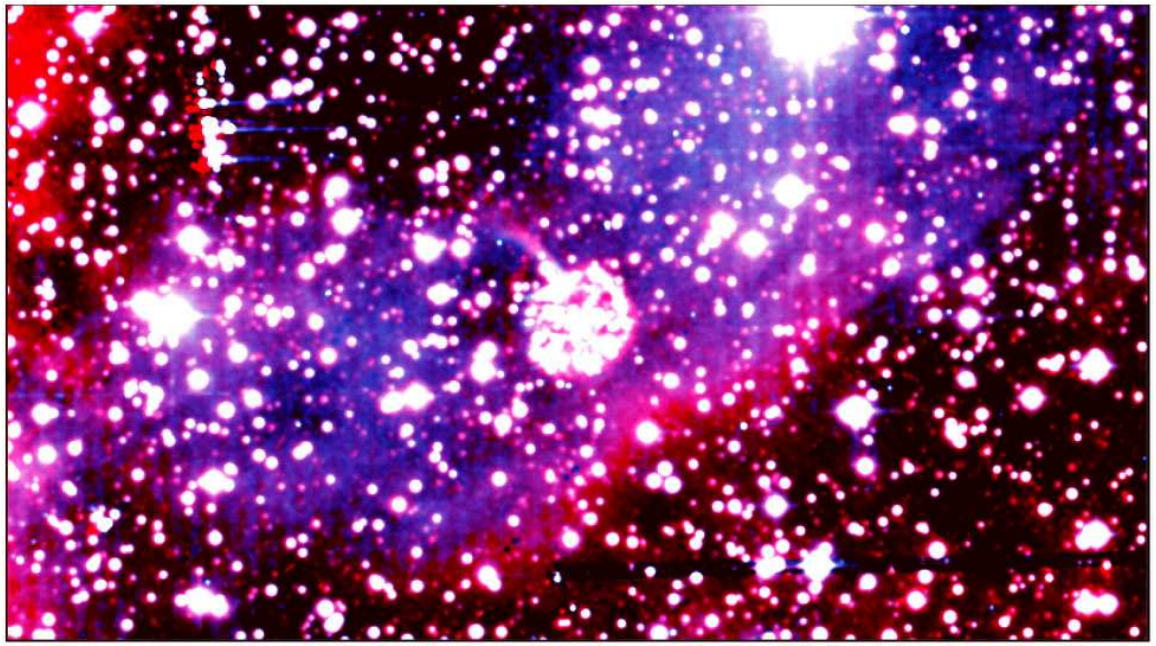
GK Per: First Interaction



- A scan of the photo of the original plate from 1917 used by Seaquist et al. 1989.
- The nova shell is clear and the ‘bar’ in the South-West is pre-existing.

Form of Ambient Medium

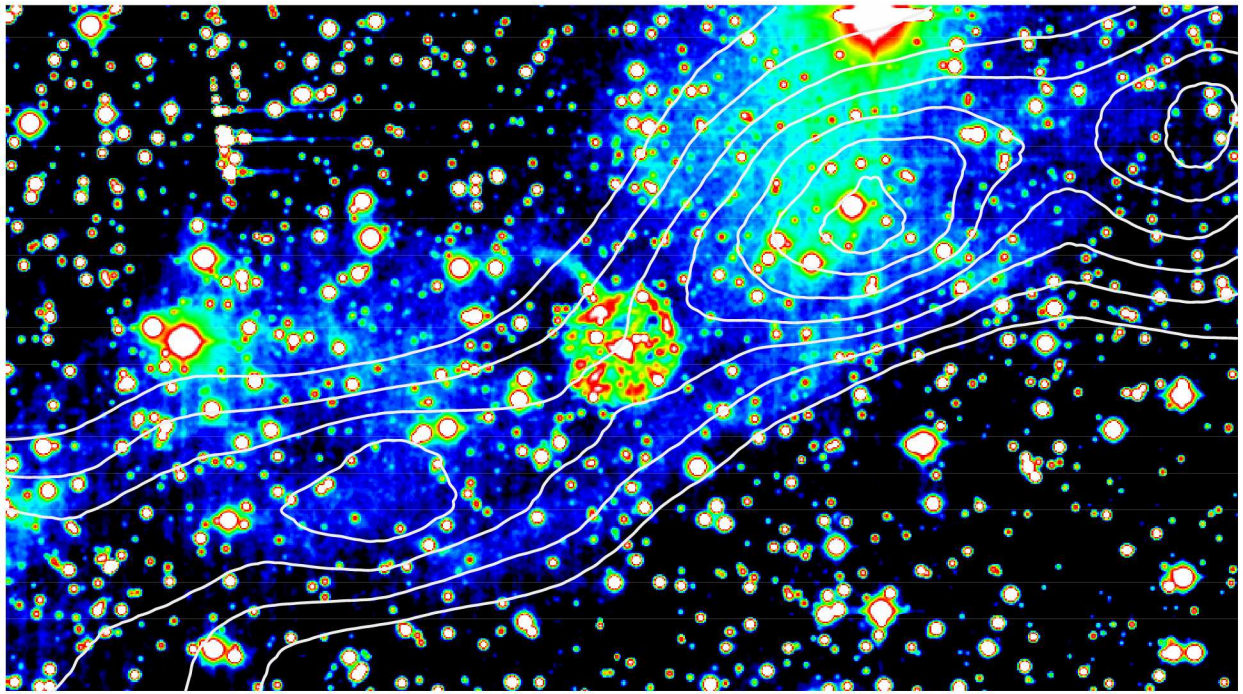
- Large scale optical nebula discovered by Tweedy (1995).
- INT WFC images (Bode, O'Brien & Simpson 2004).



- Composite of images taken through an [OIII] λ5007 filter (blue) on 2001 January 18 and Hα filter (red) on 1999 November 30. Image is 18′ x 10′ on a side, North up, East left.

Form of Ambient Medium

- [O III] λ5007 plus contours of 100 μm *IRAS* emission (Dougherty et al. 1996).



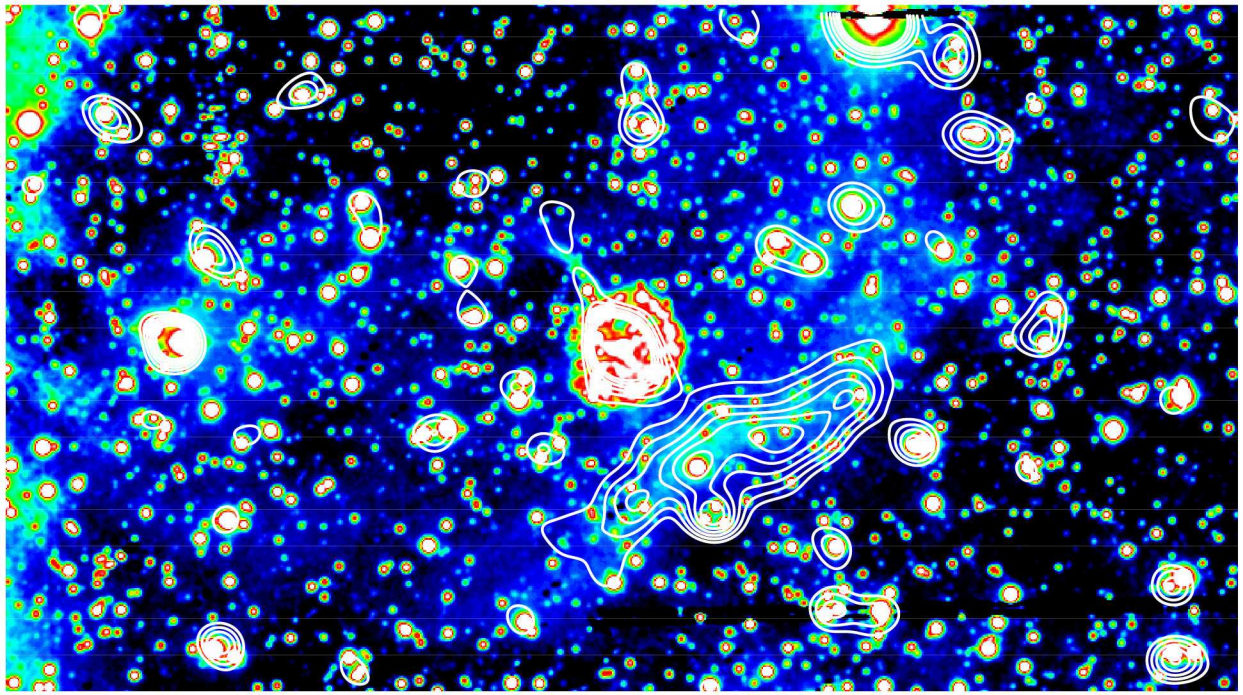
- $T_d = 23 \pm 1$K, $M_d = 0.04$ M_{sun} ($M_{HI} \sim M_{sun}$).
- Image is 18′ x 10′ on a side, North up, East left.

Form of Ambient Medium

- Large-scale nebula from previous phase of binary evolution?
- If v = 20 km/s: $t \sim 10^5$yrs; last major ejection ~ 2.8 x10^4 yrs ago (Dougherty et al. 1996).
- Suggest ejection from "born again" AGB star rather than from WD progenitor.
- Transfer rate < 10^{-7} M_{sun}/yr, intermittent burning on the WD surface in thermo-nuclear runaways, producing nova outbursts.
- Current secondary mass and spectral type + luminosity class consistent with ~ 1 M_{sun} lost.

Form of Ambient Medium

- GK Per was the first superluminal source quickly realised to be light echoes. We can now see that the source of these echoes is the large scale nebula.



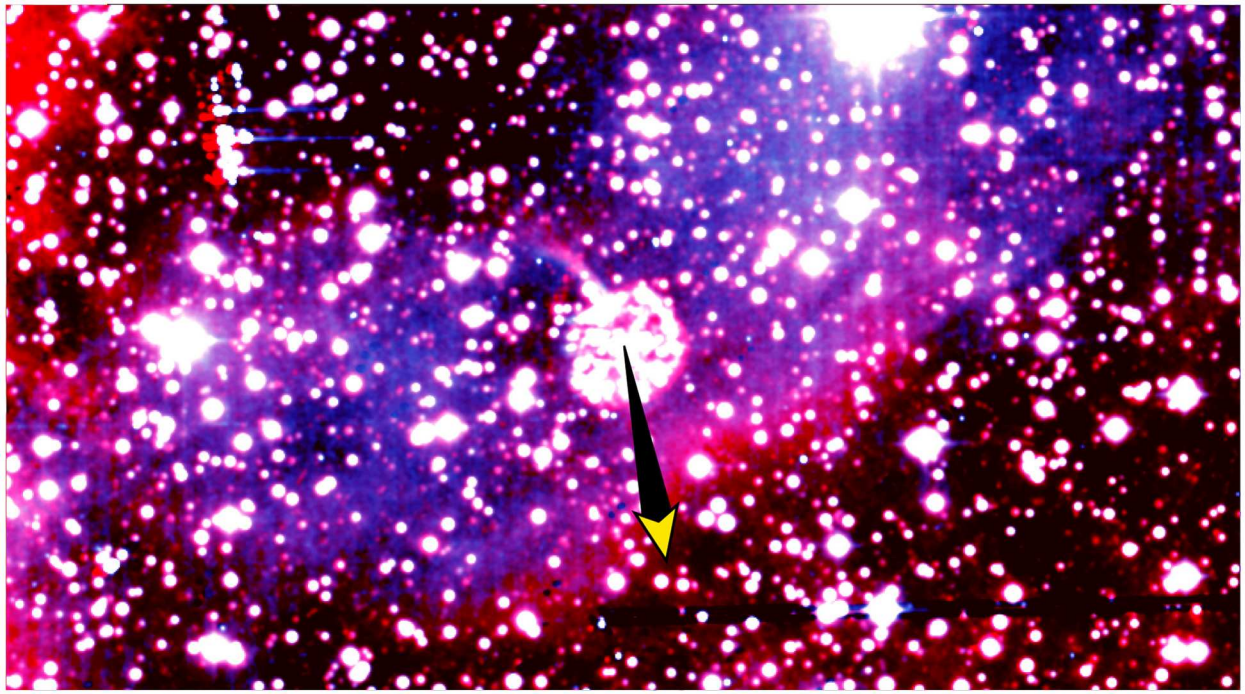
Overlay of the contours of the most persistent light echo from 1902 August 13 (Seaquist et al. 1989) on the Hα map.

Asymmetries

- **But** – what is the cause of the asymmetries?
- Have measured proper motion of central binary from 1917 – 1993 (Bode, O'Brien & Simpson 2004):

- proper motion = 0.015 ± 0.002 arcsec/yr.
- position angle = $191^{o} \pm 5^{o}$ (through East from North).
- v_s = 45 ± 4 km/s (at d = 470 pc).

Asymmetries



• Composite image of Hα and OIII with an arrow indicating the derived direction of motion of the central binary and of thickness equivalent to the estimated 1 σ error.

Numerical Simulations

- We are aiming to progressively develop a model of GK Per by modelling the following:
  - Asymmetric 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.
  - Nova explosion at wind source, in order to explore how the nova interacts with the PN.

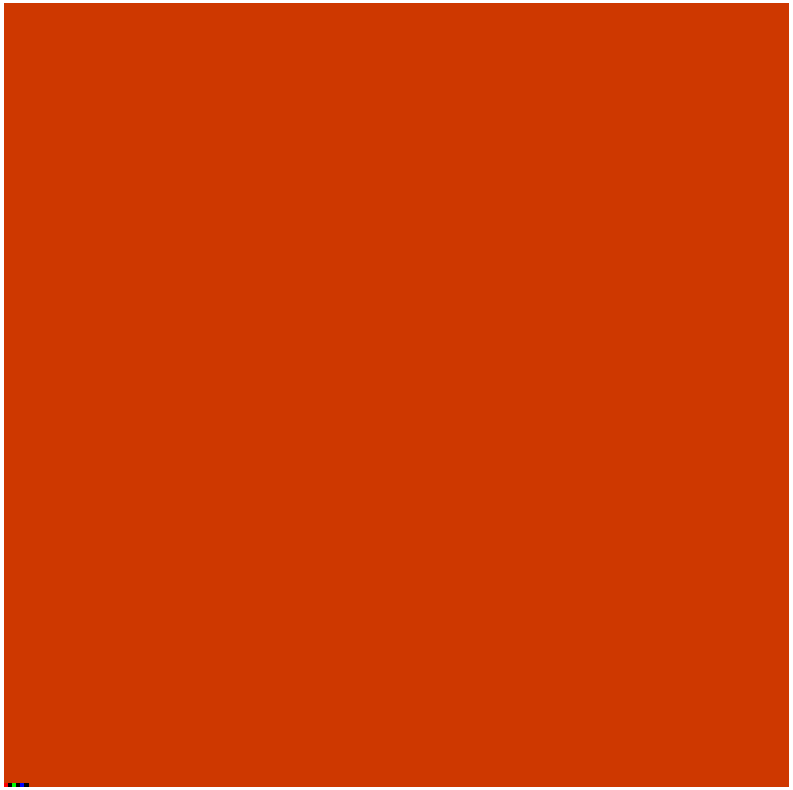
Hydrodynamic Code

- 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 using all of COBRA.
- Fully tested and memory efficient.

- COBRA; a 192-processor Beowulf cluster at Jodrell Bank.

Current status

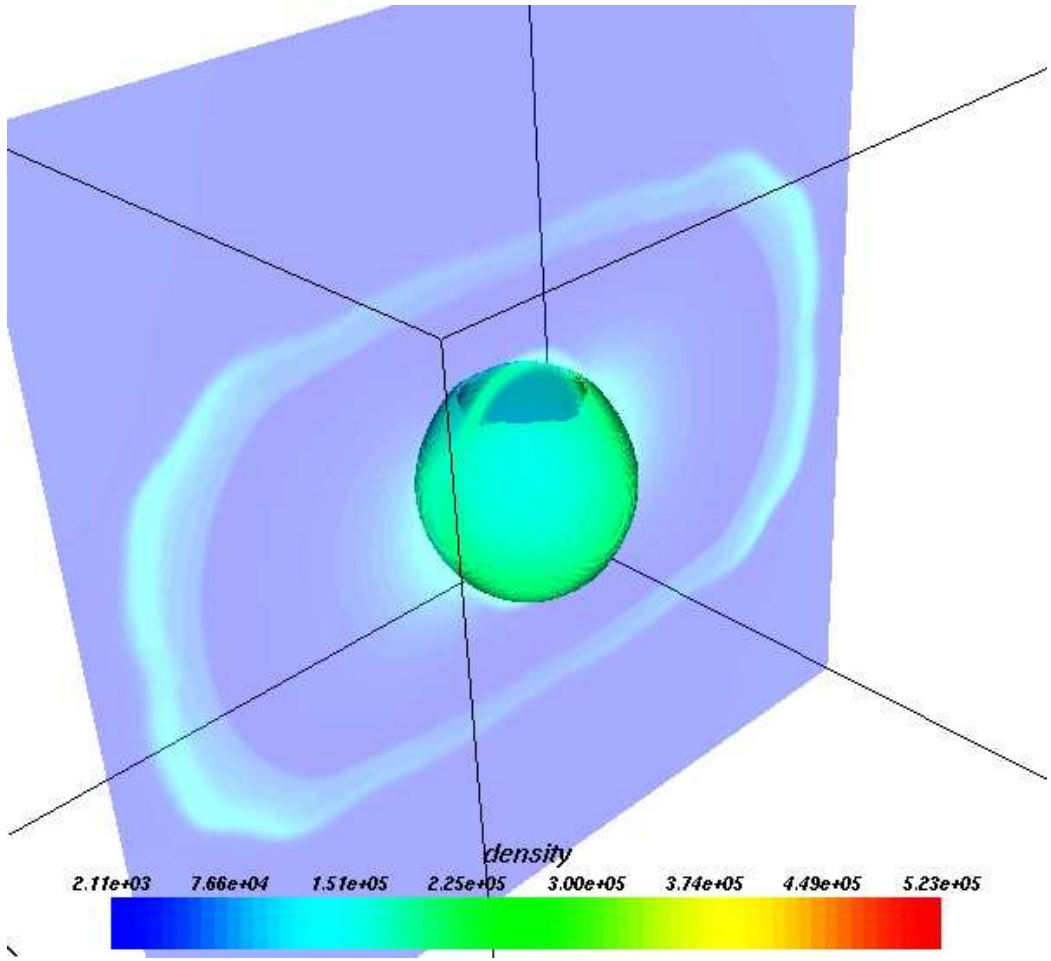
- **Note**: this is a work in progress



- $\log_{10}$ density slice of a cubic grid 4pc on each side, 200^3 resolution
- slow AGB wind (3×10^5 yrs)
  - $dM/dt = 1 \times 10^{-6}\ M_{sun}$ /yr
  - $v = 20$ km/s
  - T = 2,500 K
- fast post-AGB wind (1×10^5 yrs)
  - $dM/dt = 5 \times 10^{-8}\ M_{sun}$ /yr
  - $v = 1000$ km/s
  - T 50,000 K
- $v_{ambient} = 0$ km/s

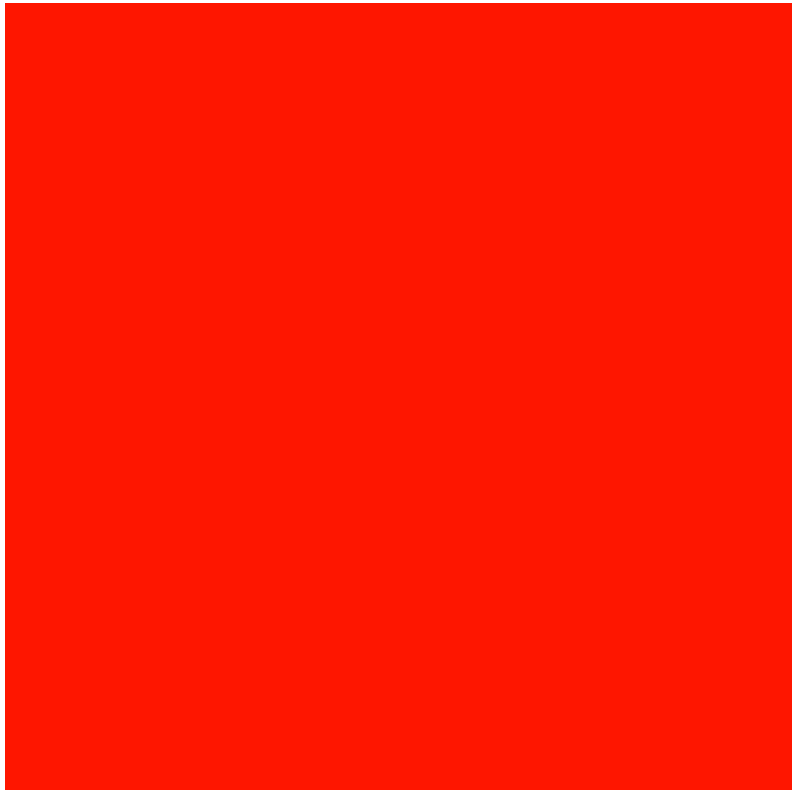
32½ hours on 10 1GHz processors on COBRA

Current status



- Density slice and high-density iso-surface suggesting the shape of the observed PN, 15,000 years after the onset of the fast wind.

Current status



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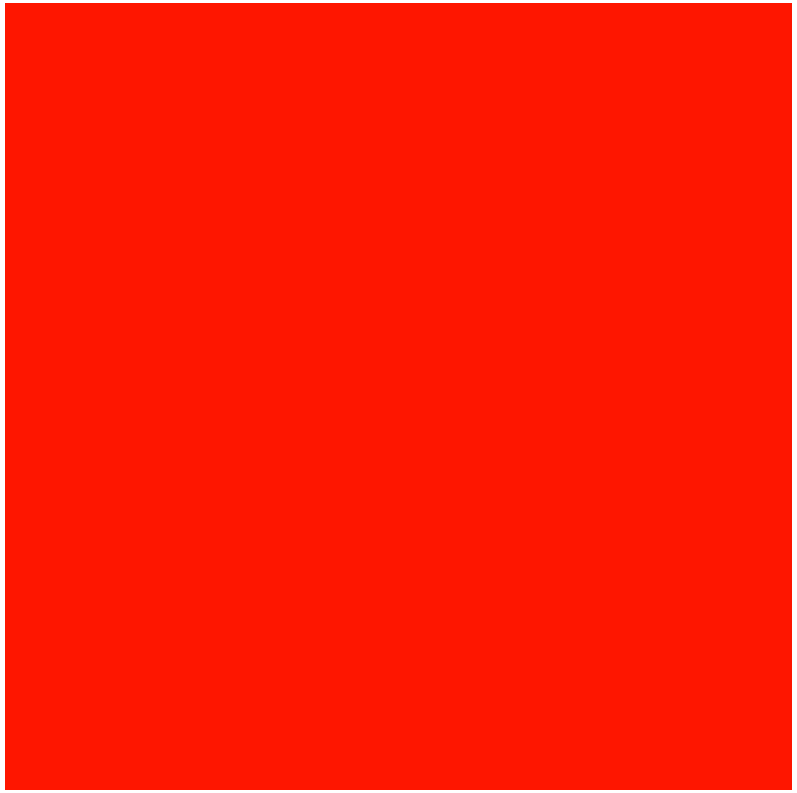
  - v = 20 km/s
  - T = 2,500 K
- fast post-AGB wind (1×10^5 yrs)
  - $dM/dt = 5 \times 10^{-8}\ M_{sun}$ /yr
  - v = 1000 km/s
  - T 50,000 K
- $v_{ambient}$ = 45 km/s

29½ hours on 10 1GHz processors on COBRA

Current status



- $\log_{10}$ density slice of a cubic grid 4pc on each side, 200^3 resolution
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- fast post-AGB wind (1×10^5 yrs)
  - $dM/dt = 5 \times 10^{-8}\ M_{sun}$ /yr
  - $v = 1000$ km/s
  - T 50,000 K
- $v_{ambient} = 45$ km/s
- $\theta_{ambient} = 340°$

29½ hours on 10 1GHz processors on COBRA

The End!