

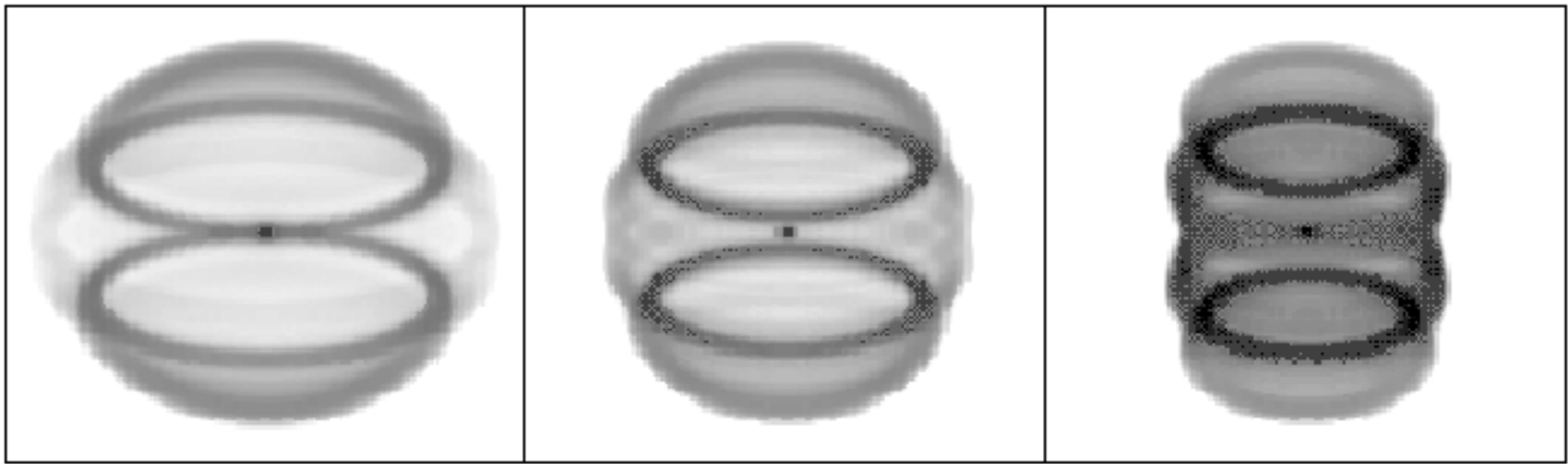
3D Hydrodynamical Simulations of PNe

Chris Wareing, Tim O'Brien and Myfanwy Bryce

Introduction

Our group has experience of making observations of planetary nebulae (see other posters by Bryce, Graham, Meaburn etc) and of numerical simulations of stellar outflows. We have applied the latter mainly to classical novae. For example, the figure below shows results from a calculation of the effects of the orbiting binary companion on the mass lost from the white dwarf star in a nova system. Here the code is 2.5 dimensional (i.e. axisymmetric but with angular momentum). This axisymmetry limits us to investigating regions of parameter space where the binary companion can be approximated as a torus, in other words the outflow speed is significantly less than the orbital speed.

Synthetic images of a 2.5D simulation of mass-loss from a classical nova (Porter, O'Brien & Bode 1998).



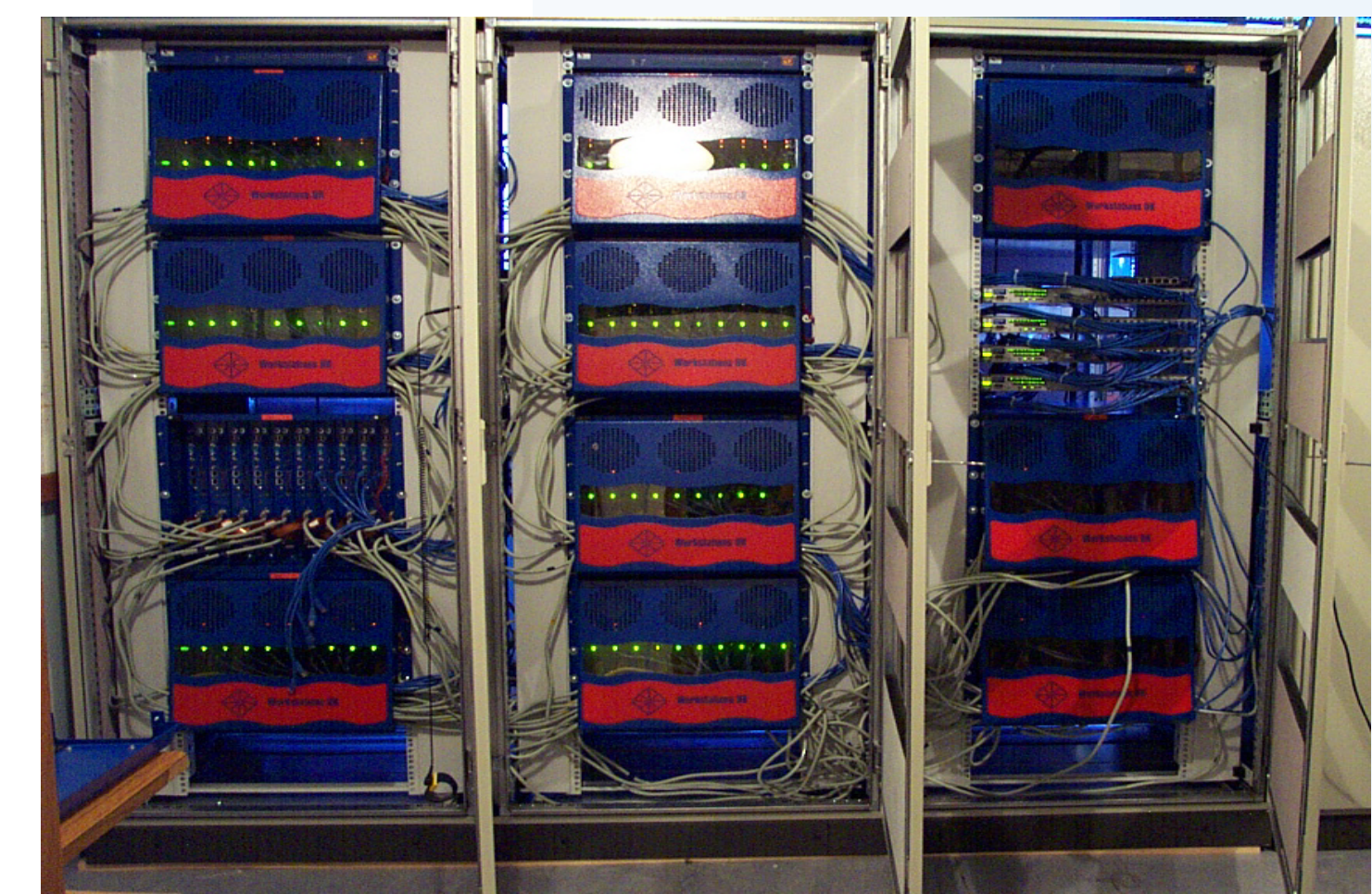
We now intend to extend these simulations to explore the development of aspherical planetary nebulae and in particular the effects of binary progenitors.

Hydrodynamic Simulations on COBRA

Until recently, we have been largely limited to two-dimensional simulations by the processor speed and amount of memory required to perform fully three-dimensional (3D) versions, but now with the development of massively parallel machines, novel numerical methods and standardised libraries of routines for communications, 3D models can be considered. This enables us to explore other regions of parameter space as in the case above or previously uninvestigated phenomena.

We have written a 3-dimensional Godonov-type finite difference code which calculates the hydrodynamics on a Cartesian grid. The code is second order in space and time except in the region of discontinuities where second order methods are unsuitable and a reduction to first order occurs.

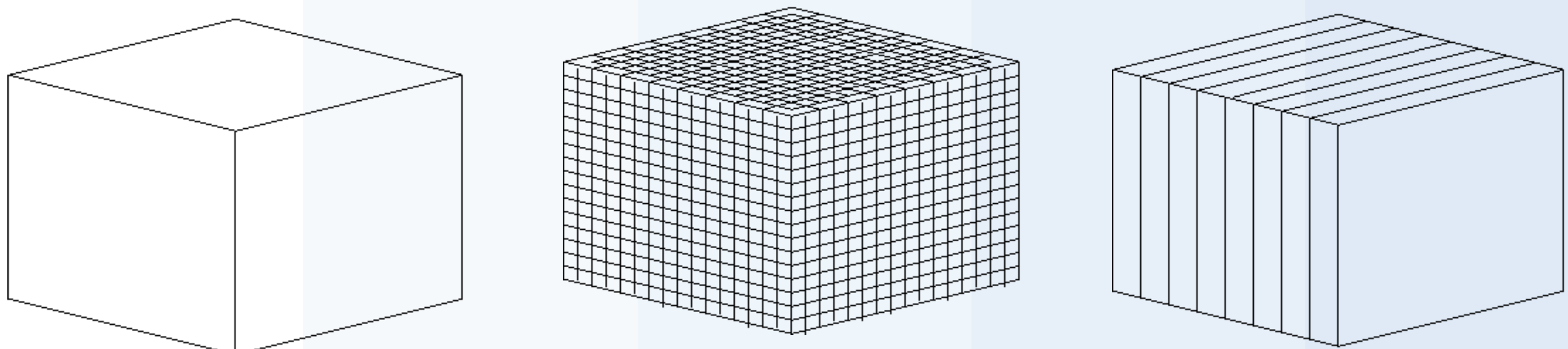
The calculations are carried out on Jodrell Bank's COBRA supercomputer. COBRA is a high-performance Beowulf-type cluster consisting of 91 dual-processor motherboards, or "nodes", each with 512 or 1024 Mb of memory and around 13Gb of disk space. The nodes are interconnected by a fast network allowing development of high-performance parallel codes using Scali MPI. Data can be stored on several high-capacity RAID arrays.



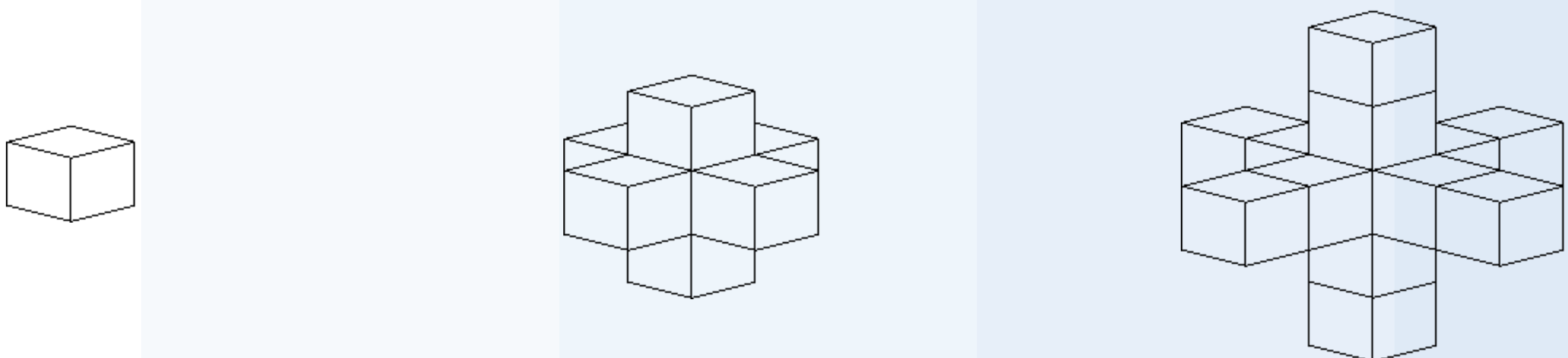
The COBRA supercomputer. The left-hand stack contains four "crates", each with 10 "nodes" (i.e. 20 processors). The motherboards of the third crate down are visible.

Parallelisation

The code is broken down and distributed amongst the nodes, or parallelised (a serial version of this code is described in Higgins, O'Brien & Dunlop 1999). Currently, the full grid is setup on every node, but following that, each node only handles a specific portion of the grid. The grid is split into approximately equal slices (shown below), the size of which is inversely proportional to the number of nodes involved in the simulation. As the nodes need to communicate boundary information between each other, this approximately equal distribution ensures no specific node delays the calculations.



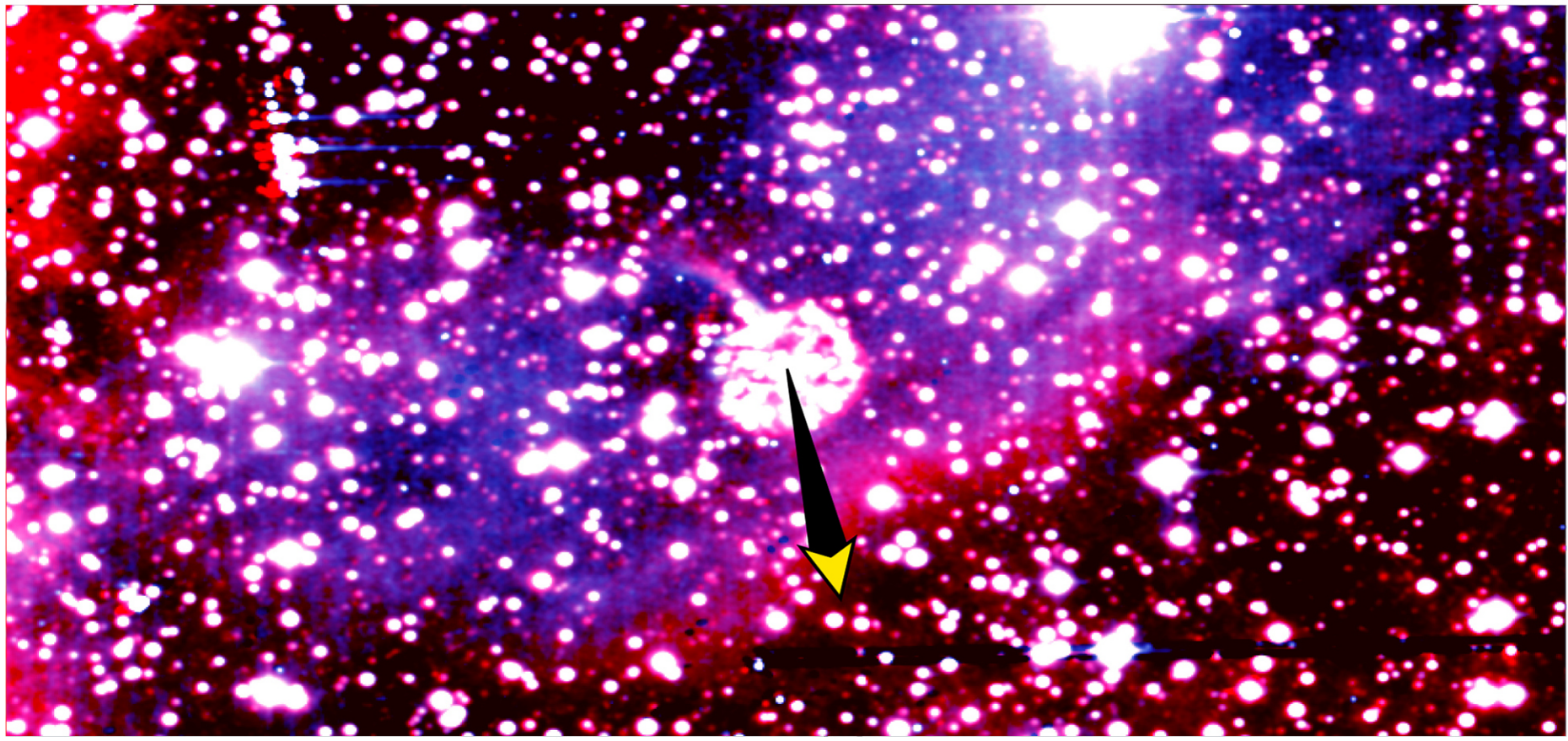
The left hand figure above shows the cube of the whole grid of the simulation, which is broken down into cells (central figure). These cells are then shared out in slices of the whole grid (right hand figure) across the processors of the supercomputer.



Each cell (left hand figure) builds up the fluxes coming into and out of it in two steps. A first order step considers the fluxes from one cell in every direction (central figure). A second order step then considers the fluxes from two cells in every direction

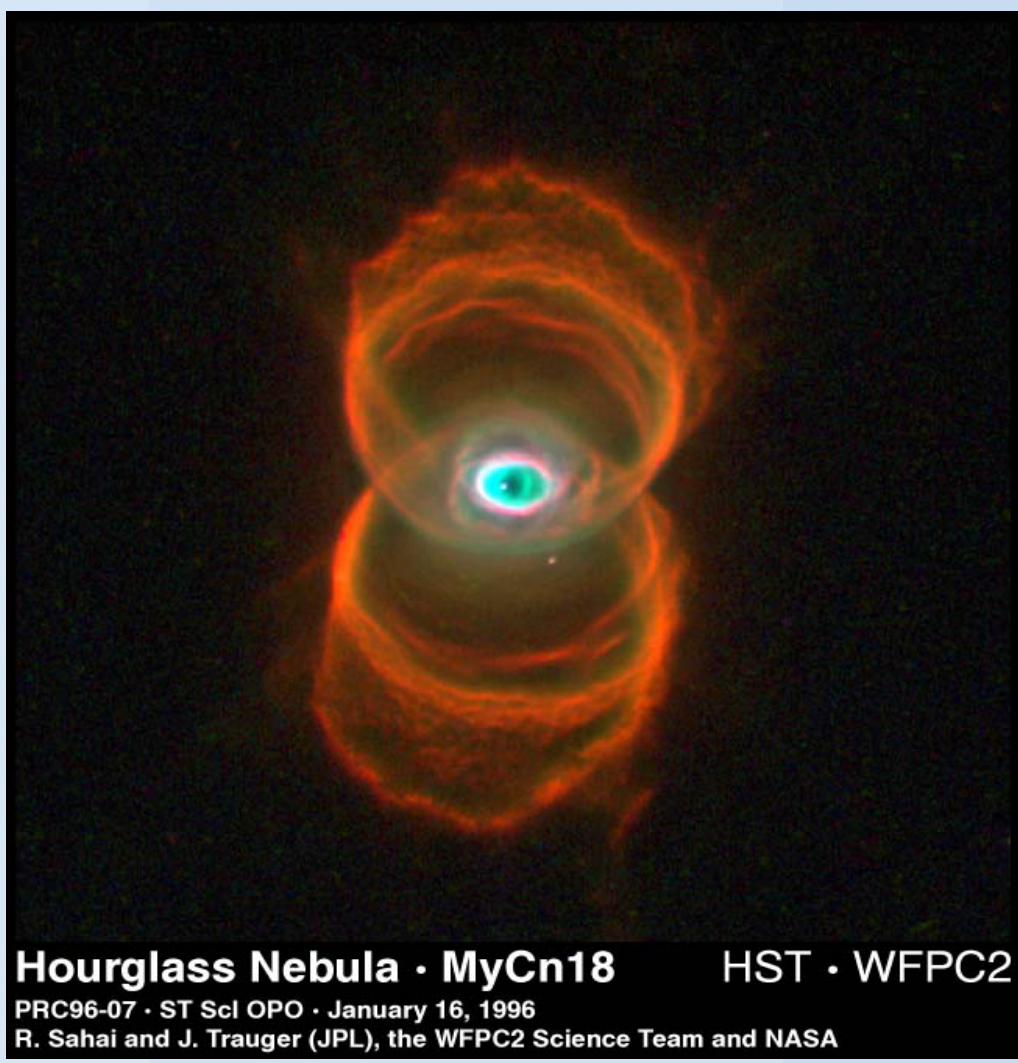
Planetary Nebulae

The classical nova GK Per, which outburst in 1901, appears to be embedded in an ancient planetary nebula (Tweedy 1995). It has recently been found that the PN is shaped by the motion of the central binary system through the ISM (see figure below). The nova ejecta are now sweeping up the PN resulting in X-ray and non-thermal radio emission from the shock interaction region. We intend to model this interaction by first investigating the development of the PN as the central binary moves through the ISM and then setting off a nova explosion at its centre.



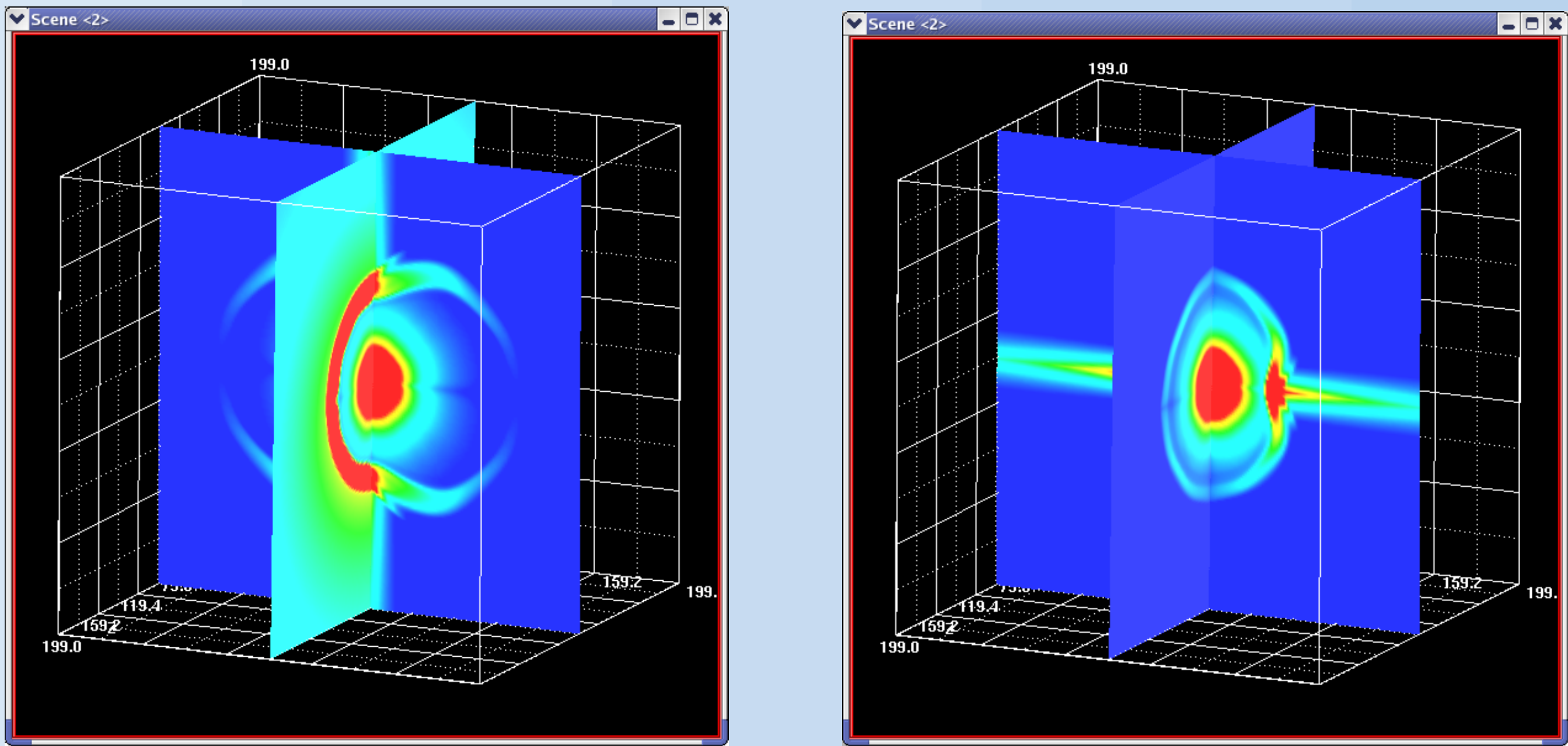
Isaac Newton Telescope Wide Field Camera images of the classical nova GK Per (Bode, O'Brien & Simpson 2003). This shows the 1901 nova ejecta (white material at the centre) running into the ancient bipolar planetary nebula previously ejected by the white dwarf. The arrow shows the proper motion of the central binary system.

We are also modelling the hourglass-shaped nebula MyCn18 (see figure below). This nebula has been spatio-kinematically modelled with the nebula lobes presented as thin-walled structures in the shape of modified paraboloids (Dayal et al 2000) consistent with the general predictions of the interacting winds hypothesis.



HST WFPC2 image of the young planetary nebula MyCn18 (Sahai et al 1999).

Our initial models have been used to test the new 3D parallel code and simulate the outflow of a wind into an asymmetric ambient medium - see figures below. The next step is to introduce a binary companion and investigate its effects on the slow wind before sweeping up the resulting density distribution in a fast-wind phase.



These two figures show orthogonal slices through the density distribution from simulations on a 200x200x200 grid. In each case a 10 km/s wind is blown through a stationary ambient medium. In the simulation on the left the density profile of the ambient medium varies from $1/r$ in the vertical plane shown as pale green to $1/r^8$ along the axis orthogonal to this plane (i.e. running horizontally through the centre of the blue plane). This is equivalent to a wind blowing into a disc-like density distribution and results in a bipolar wind. In the simulation on the right the variation in the density of the ambient medium is reversed and so the higher density is "rod-like" lying along the horizontal axis through the centre of the plane approximately in the plane of the page.

References

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