Orszag-Tang Vortex Test

Reference:

The problem was first studied by Orszag & Tang (J. Fluid Mech., 90, 129, 1998). Since then it has been extensively compared in tests of numerical MHD simulations. A few such examples include Zachary et al. (JSC, 15, 263, 1994), Ryu et al. (ApJ, 452, 785, 1995 and ApJ, 509, 244, 1998), Dai & Woodward (ApJ, 494, 317, 1998), Jiang & Wu (JCP, 150, 561, 1999), and Londrillo & Del Zanna (ApJ, 530, 508, 2000). The problem was also studied as a model for 2-D turbulence by Dahlburg & Picone, Phys. Fluid B, 1, 2153 (1989) and Picone & Dahlburg, Phys. Fluid B, 3, 29 (1991), using Fourier spectral methods.

Description:

We use a square domain, $0 \le x \le 1$; $0 \le y \le 1$. The boundary conditions are periodic everywhere. The density ϱ is $25/(36\pi)$ and the pressure is $5/(12\pi)$ everywhere, and $\gamma = 5/3$. Note that this choice gives $c_s^2 = \gamma P/\varrho = 1$. The initial velocities are periodic with $V_x = -\mathrm{Sin}(2\pi y)$ and $V_y = \mathrm{Sin}(2\pi x)$. The magnetic field is initialized using a periodic vector potential defined at zone corners; $A_z = B_0\,(\mathrm{Cos}(4\pi x)/(4\pi) + \mathrm{Cos}(2\pi y)/(2\pi))$, with $B_0 = 1/(4\pi)^{1/2}$. Face-centered magnetic fields are computed using $B = \nabla \otimes A_z$ to guarantee $\nabla \cdot B = 0$ initially. This gives $B_x = -B_0\mathrm{Sin}(2\pi y)$ and $B_y = B_0\mathrm{Sin}(4\pi x)$.

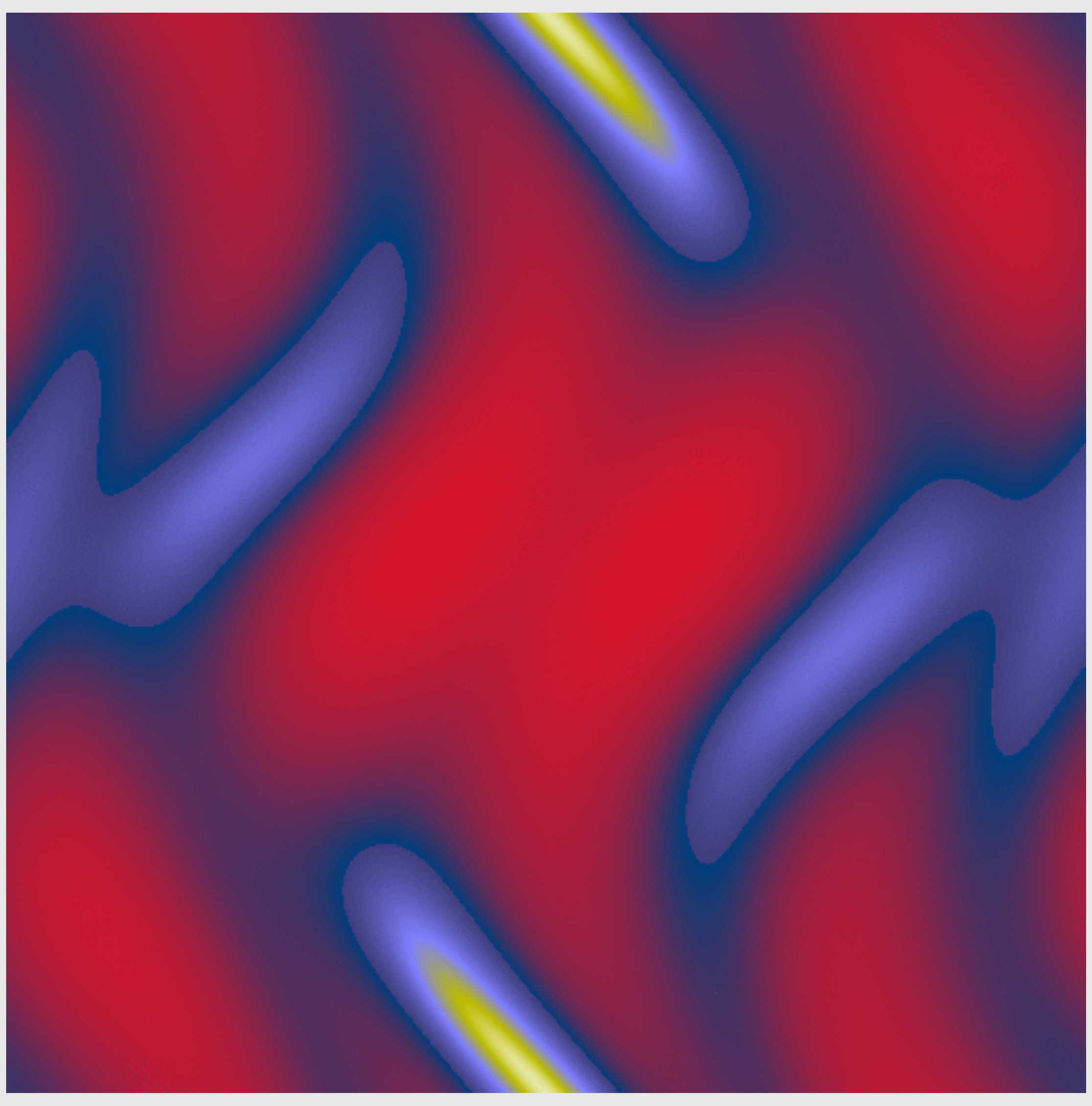
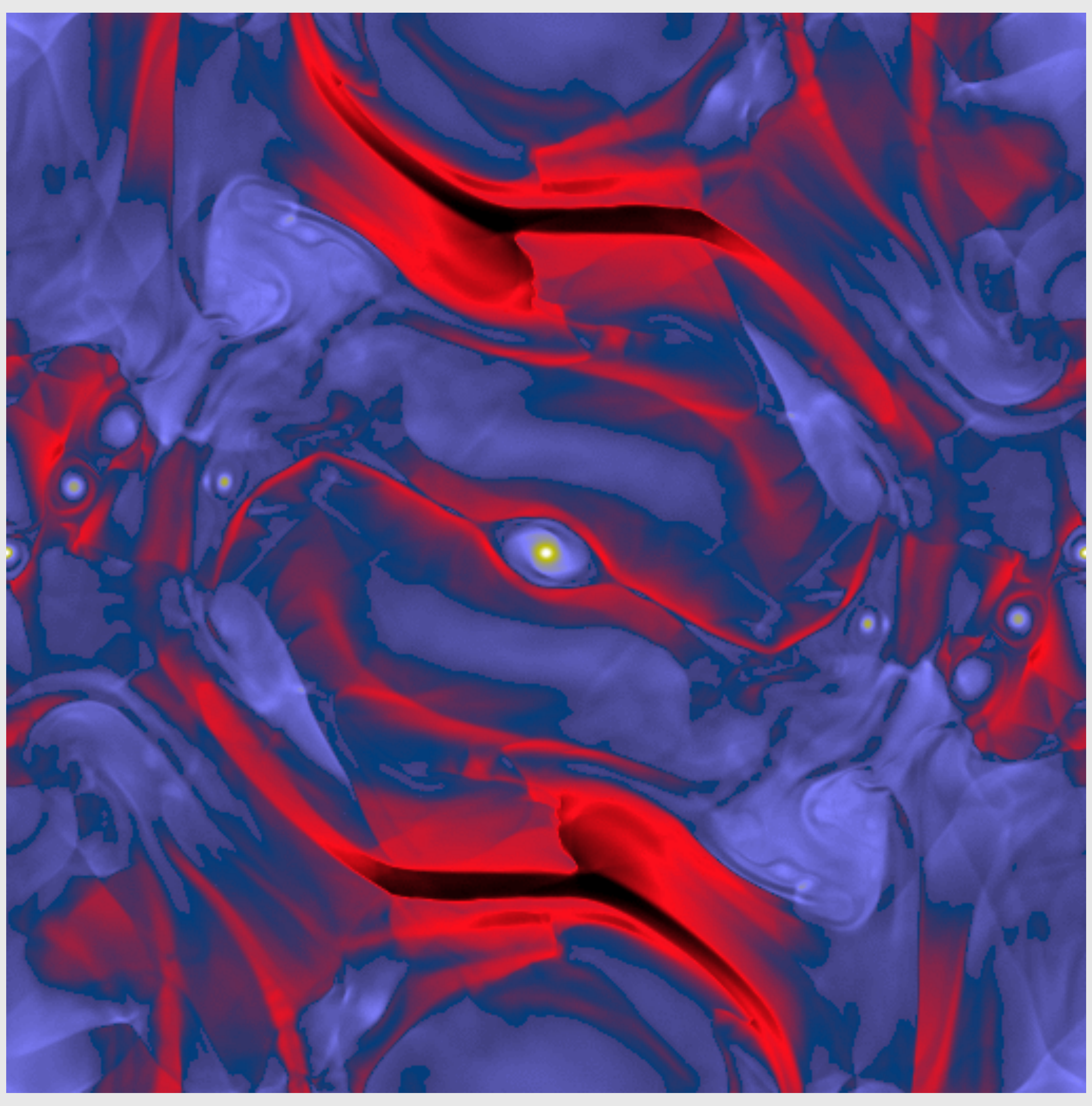
What's important about this test?

The Orszag-Tang vertex is a well-known model problem for testing the transition to supersonic 2D MHD turbulence. Thus, the problem tests how robust the code is at handling the formation of MHD shocks, and shock-shock interactions. The problem can also provide some quanititative estimates of how significant magnetic monopoles affect the numerical solutions, testing the $\nabla \cdot B = 0$ condition. Finally, the problem is a very common test of numerical MHD codes in two dimensions, and has been used in many previous studies. As such, it provides a basis for consistent comparison of codes.

Results: 2D MHD

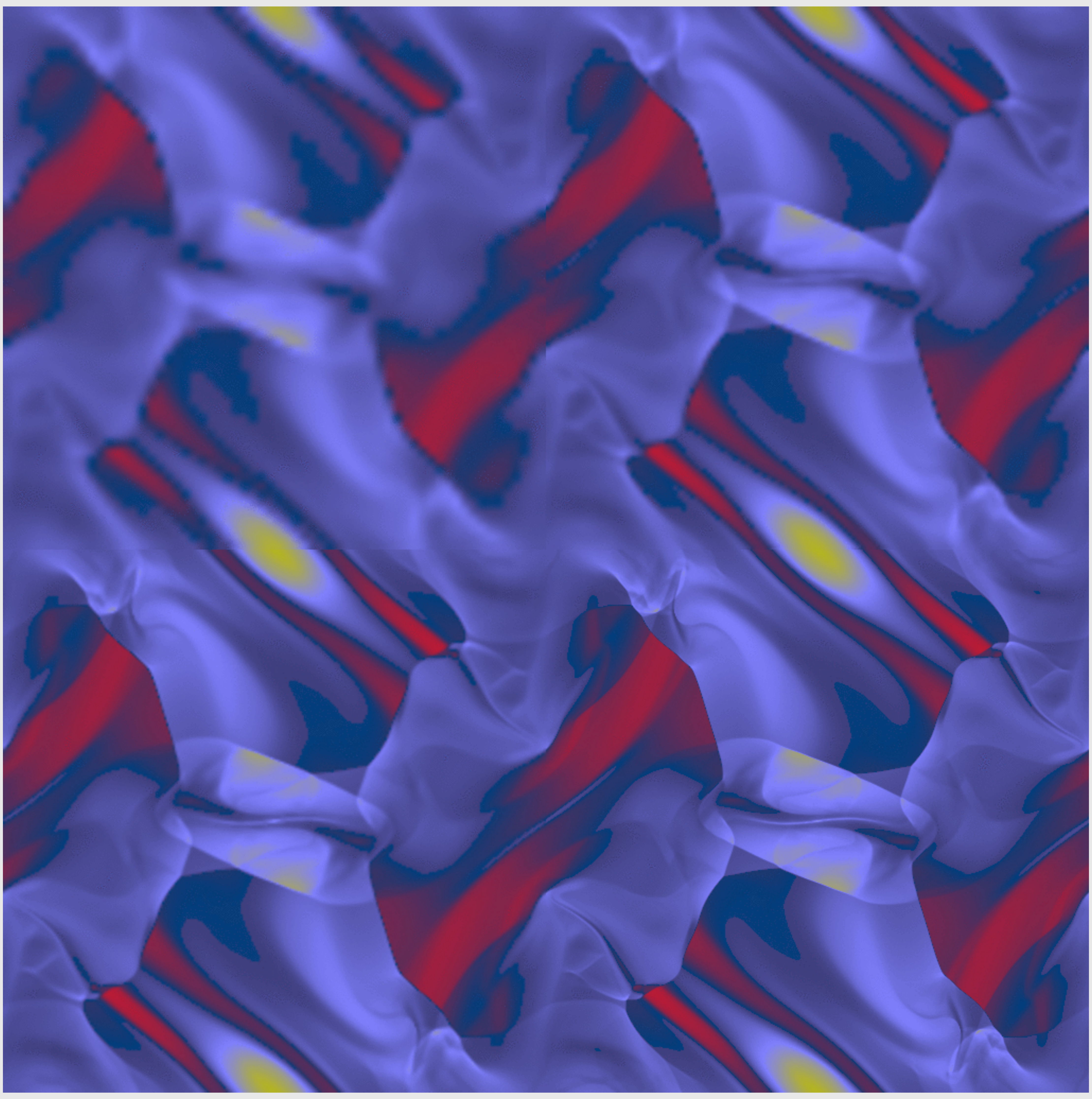
Results computed with Athena using the Roe solver and the third order algorithm on a 512x512 grid are shown below at time=0.1 (on the left), and time=1.0 (on the right). The images show the pressure on a linear color map between 0.01 and 0.7.

Click on the right image to download a .gif movie (28.8 MB).

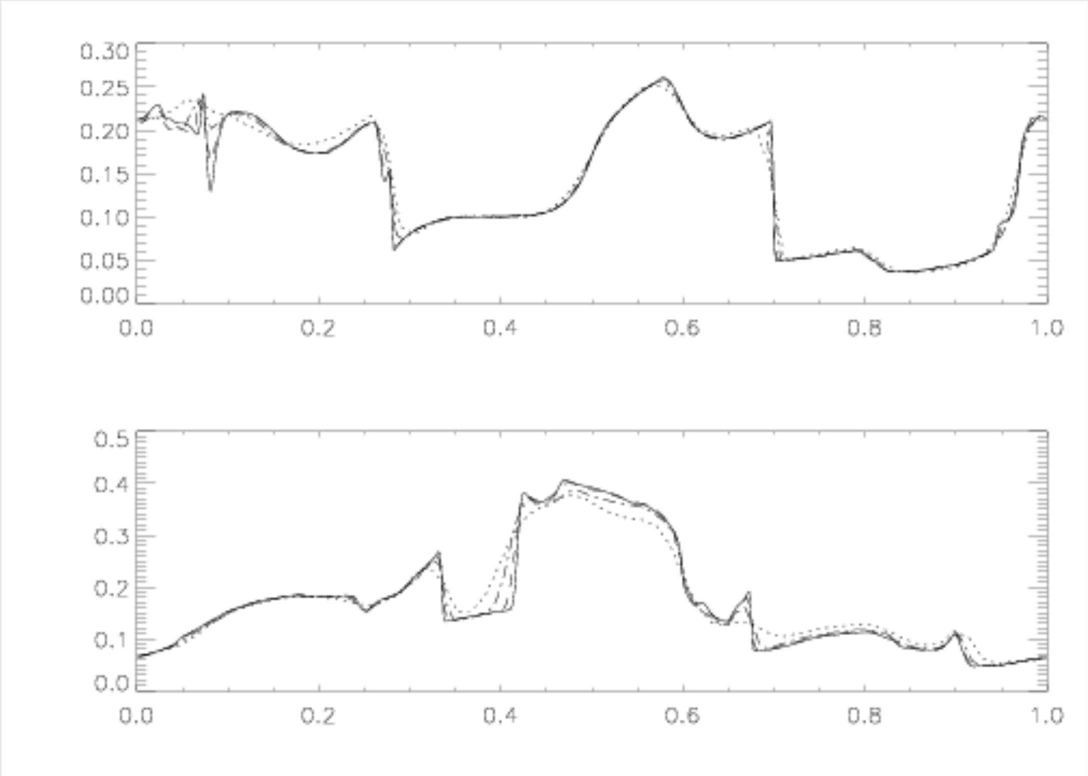
The results for time=0.5 are shown below for a 64x64 grid (upper left), 128x128 grid (upper right), 256x256 grid (lower left), and 512x512 grid (lower right). The images show the density on a linear color map. (Note the image below contains all four results joined into one 1024x1024 image.)

They can be compared to Figure 6 of Dai & Woodward (1998), Figure 10 of Londrillo & Del Zanna (2000), and Figure 3 of Ryu et al. (1998) (taken at time=0.48).



For more quantitative comparisons between schemes, we plot the value of the pressure in horizontal slices along y = 0.4277 and y = 0.3125 at time = 0.5. The horizontal axis is the x-axis and the vertical axis is the normalized pressure P. The results are shown for a 64x64 grid (dotted line), 128x128 grid (dot-dash line), 256x256 grid (dashed line), and 512x512 grid (solid line).

They can be compared to Figure 11 of Londrillo & Del Zanna (2000) and Figure 3 of Ryu et al. (1998) (taken at time=0.48) (see also Jiang & Wu 1999).



Page by Philip Hopkins, July 2004.