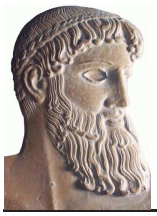
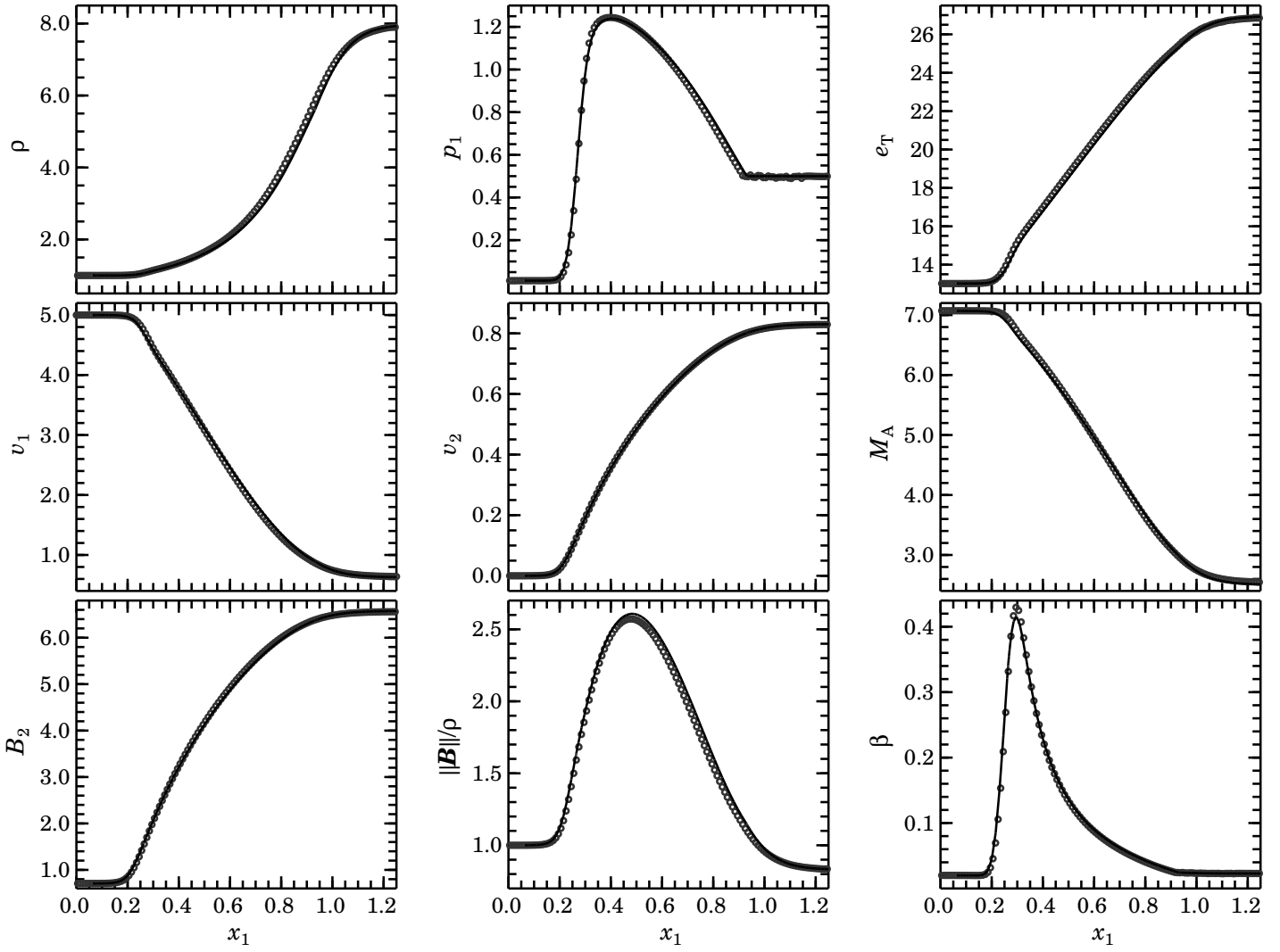


ZEUS-3D 1-D Gallery #23: Adiabatic C-shock with Ambipolar Diffusion



New to version 3.6 is a one-fluid model for *ambipolar diffusion* (AD, Duffin & Pudritz, 2008, MNRAS, 391, 1659), a mechanism by which magnetic field lines can "slip" relative to the rest frame of an incompletely ionised fluid.

In the panels, open circles represent the `dzeus36` solution for the adiabatic AD-MHD shock tube problem with left state $(\rho, v_1, v_2, v_3, B_2, B_3, p_1) = (1, 5, 0, 0, 1/\sqrt{2}, 0, 0.01)$, right state $(7.976, 0.627, 0.830, 0, 6.576, 0, 0.5)$, $B_1 = 1/\sqrt{2}$ and $\gamma = 5/3$ at time $t = 4$. `CMoC` is used with the internal energy equation (`itote=0`), second order interpolation (`iord=2`), artificial viscous parameters `qcon=1` and `qlin=0.2`, and the Courant number is set to `courno=0.75`. Most variable names are self-explanatory, with $\beta = 2p_1/B^2$ in the lower right panel. The domain $0 \le x_1 \le 1.5$ is resolved with 150 zones with only $0 \le x_1 \le 1.25$ shown and, at $t = 0$, the discontinuity is at $x_1 = 0.5$. The units are not scale-free, and additional `dzeus36` parameters needed for this problem are: `gammaad=1.0e6`, `mpnp=1.0`, `ionconst=1`, and `dscale=1.0e-5` (see the associated `dzeus36.s` file).

The initial discontinuity launches numerous transients and, after ∼1,500 MHD cycles, the solution begins to converge to a steady state. The panels shown are after ∼2,800 MHD cycles and exhibit a so-called adiabatic *C-shock* (continuous shock; as opposed to a *J-shock*, or jump shock), whose continuous

nature is a direct consequence of AD, a process with a time-scale $\sim 1\%$ that of ideal MHD.

To run the simulation on the AD time-scale (`iscyad=0`) requires more than 250,000 time steps and nearly 40 s CPU on a standard (circa 2012) Macbook Pro. To alleviate this, *ZEUS*' old subcycling algorithm for two-fluid diffusion (`iscydf`) and artificial viscosity (`iscyqq`) has been adapted for AD (`iscyad=1`) to run on the MHD time scale, and requires $\sim$2,800 time steps and < 10 s CPU to complete. Better still, *super-stepping* (`iscyad=2`; Meyer, Balsara, & Aslam, 2012, MNRAS, 422, 2102) using *Richardson extrapolation* for rapid convergence has been implemented and was used to generate the panels above. This is a second order sub-cycling algorithm that also requires $\sim$2,800 MHD time steps and < 3 s CPU to complete. Regardless of `iscyad` and `itote`, all 1-D simulations are qualitatively *identical*.

Semi-analytical solutions generated within `dzeus36` using a sixth-order Runga-Kutta scheme are overlaid; differences between numerical and analytical solutions for no sub-cycling are less than 1% everywhere and in most places, $< 0.1\%$. With sub-cycling, errors can be as high as 2%.