# Testing electron heating in the relativistic fluid code KHARMA

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# KHARMA

- Relativistic Fluid Code

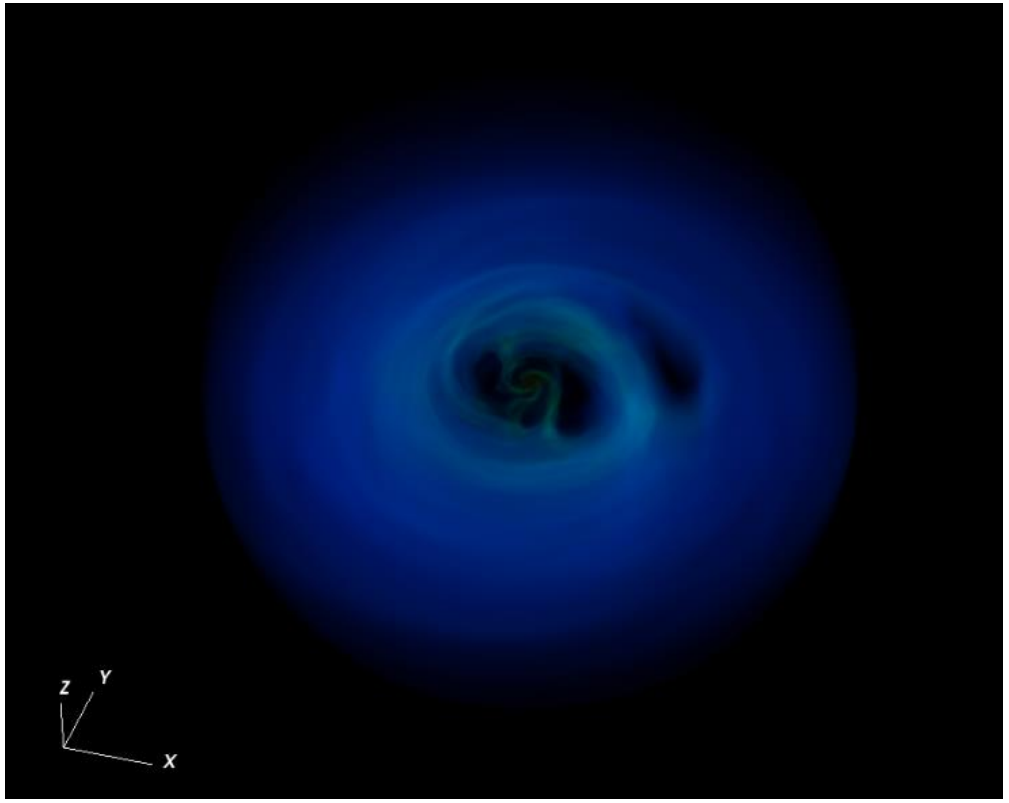



Image generated by Ben Prather

# ipole

- Radiative Transfer Code

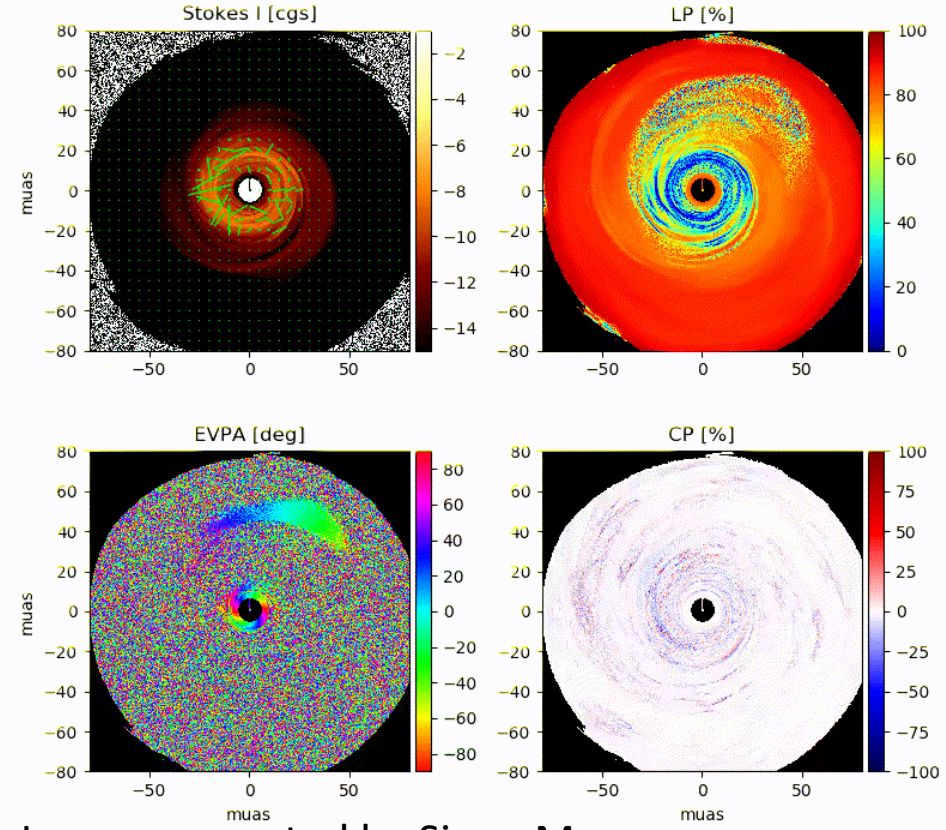



Image generated by Signe Mason

# Implementation

- Previous work with $R_{high}$ $\quad \frac{T_p}{T_e} = R_{high}\frac{\beta^2}{1+\beta^2} + R_{low}\frac{1}{1+\beta^2}$
- Tracking entropy of the whole fluid to determine its dissipation

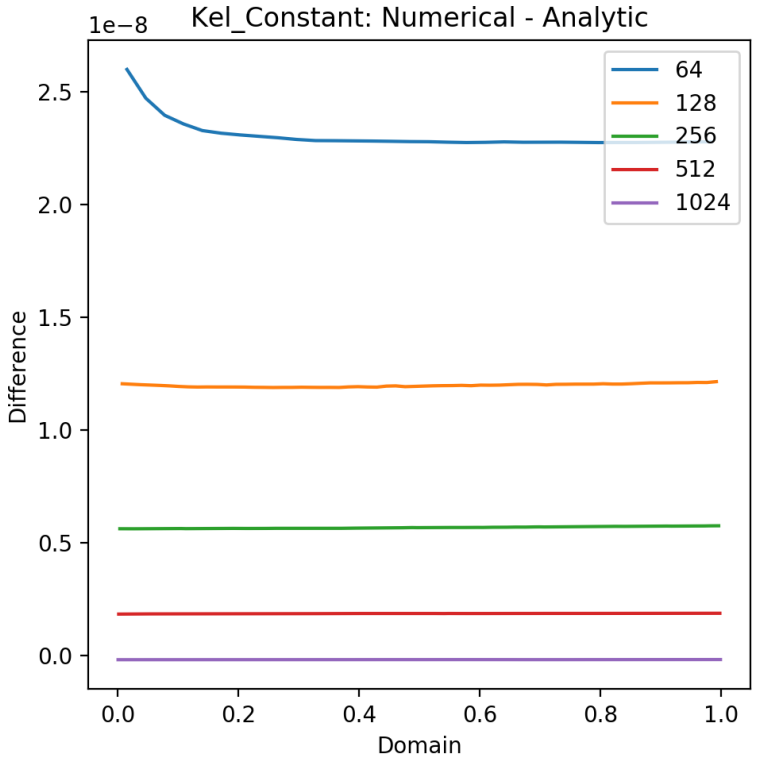
$$Q = \rho T_g u^\mu \partial_\mu s_g \rightarrow Q = \left(\frac{\rho^{\gamma-1}}{\gamma-1}\right)^{n+1/2}\left[\frac{\rho u^t\left(\kappa_g - \hat{\kappa}_g\right)}{\Delta t}\right]^{n+1}$$

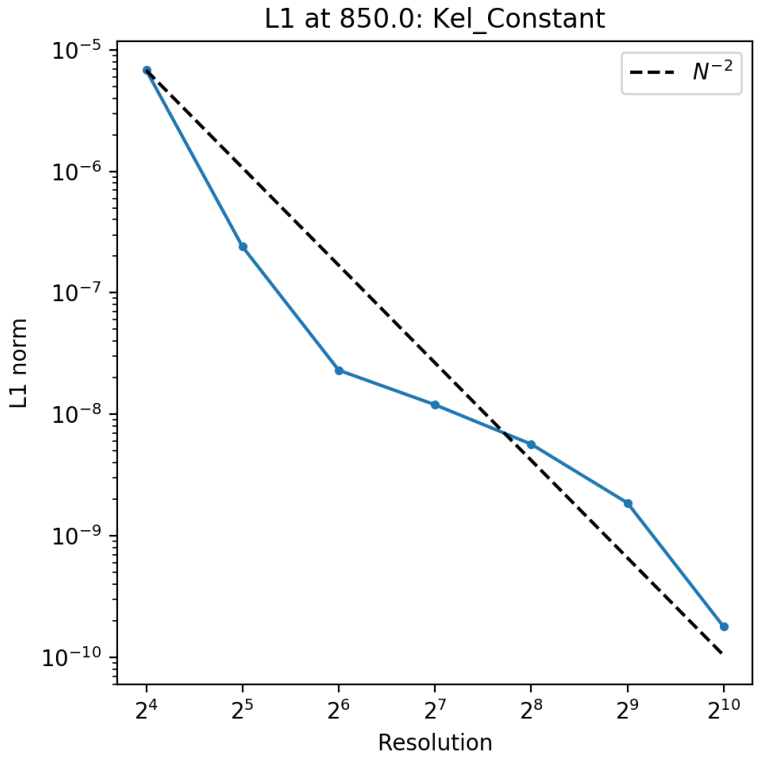
where $k_g \equiv P_g\rho^{-\gamma}$ and $P_g = (\gamma-1)u_g$

Finally, we assign a fraction of the heating of the whole fluid to the electrons: $Q_e = f_e Q$

# Hubble Flow Test, 1D

- Testing that it has a 2nd order convergence.
- Setting $v = \frac{v_0 x}{1+v_0 t}$ and a explicit heating term $Q = \frac{u_0 v_0 (\gamma-2)}{1+v_0 t^3}$
- Analytically, the electron entropy is: $\kappa_e = \frac{(\gamma-2)(\gamma_e-1)}{\gamma_e-2} \frac{u_0}{\rho_0^{\gamma_e}} \frac{1}{(1+v_0 t)^{2-\gamma_e}}$

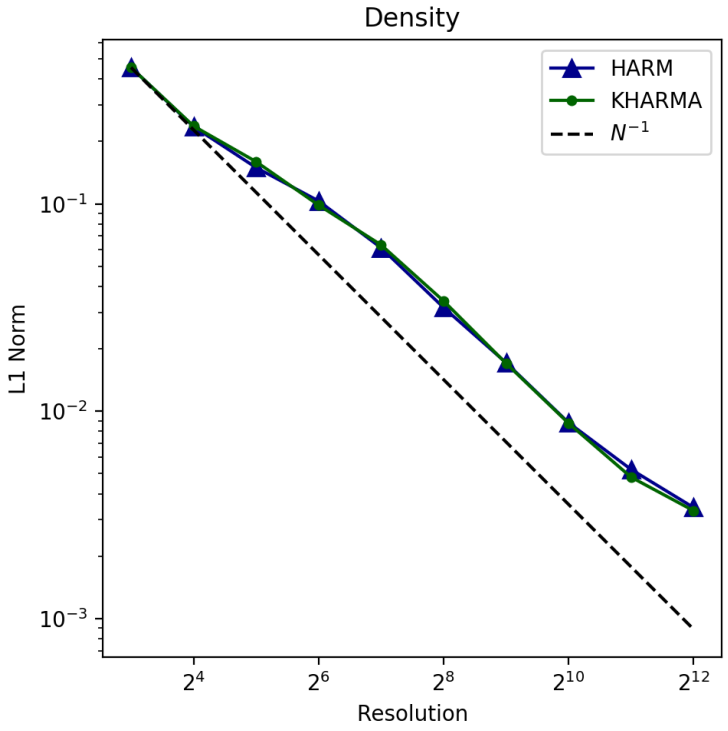


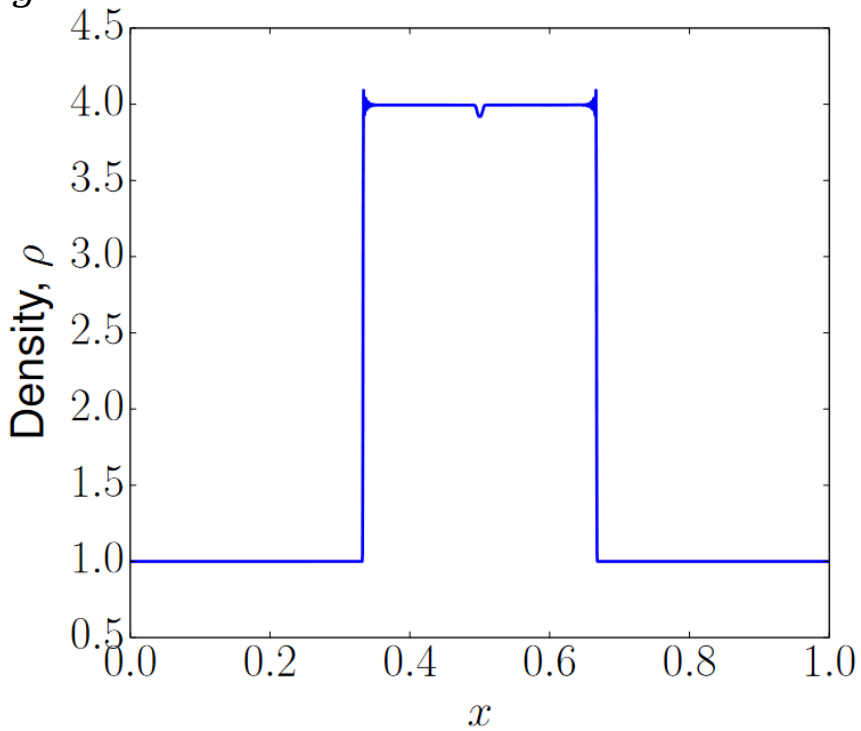



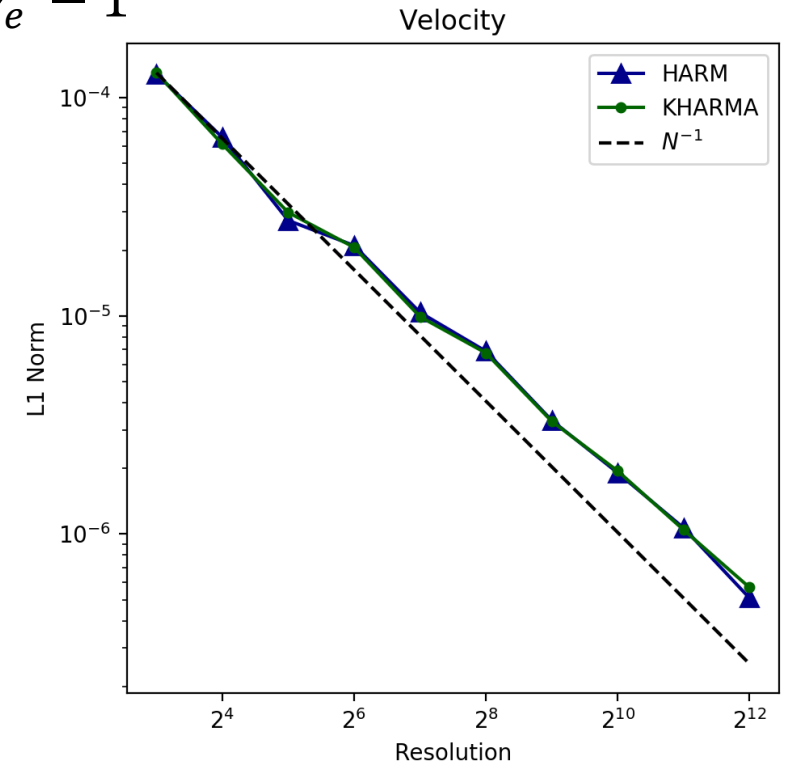
# Noh Shock Test, 1D

- Testing that it captures shocks at 1st order convergence.
- Initial condition: Velocity is discontinuous at the center, $v_l = -v_r > 0$
- Assuming a high Mach Number:

$$\frac{u_e^f}{u_g^f} = \frac{f_e}{2}\left[\left(\frac{\gamma+1}{\gamma-1}\right)^{\gamma_e}\left(1-\frac{\gamma}{\gamma_e}\right)+1+\frac{\gamma}{\gamma_e}\right]\frac{\gamma^2-1}{\gamma_e^2-1}$$

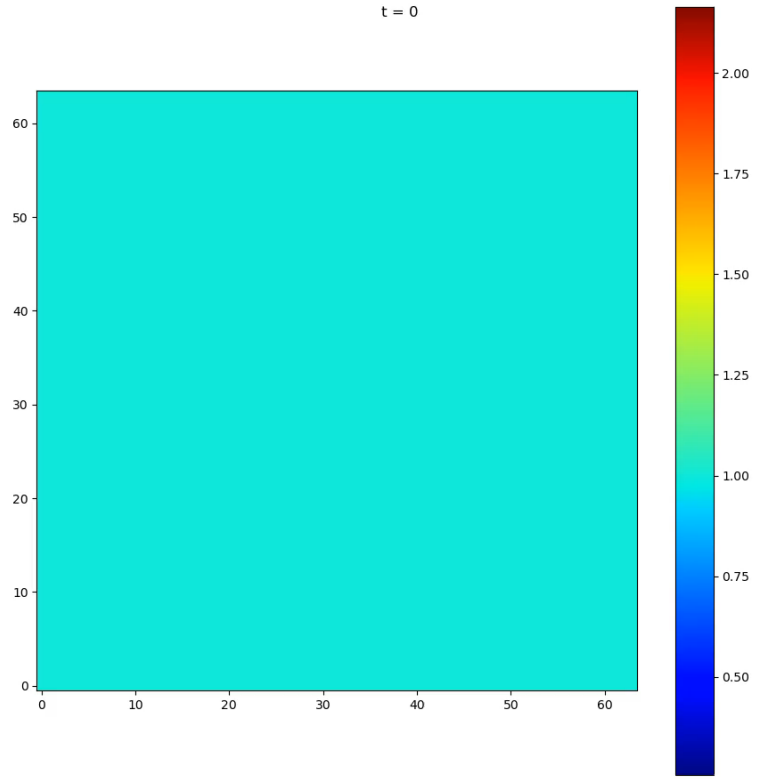


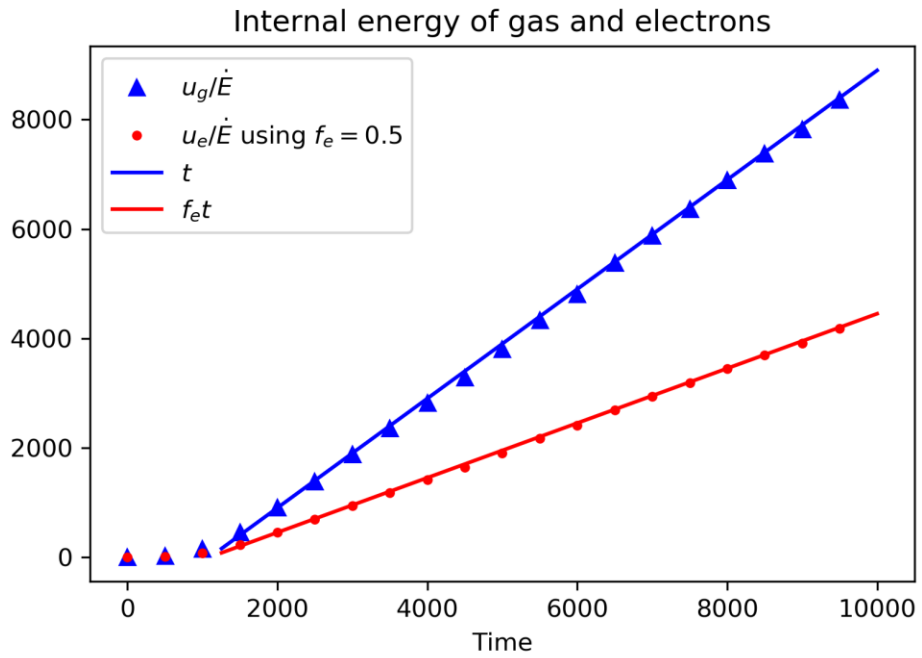



# Driven Turbulence Test, 2D

- Inject energy to a fluid in a periodic box at a constant energy rate $\dot{E}$
- Total internal energy change should reflect this rate.
- Gaussian random kicks from a GRF with variance $\sigma^2 \propto k^6 \exp\left(-\frac{8k}{k_{peak}}\right)$



# What's next?

- Using plasma models to determine the fraction of heating, $f_e$, that would go to electrons at each cell
- Application to Sgr A* models
- Questions