Week 2 Report

Sam Frederick

Goals from Last Week

- Steps to Replicating Kuhn's Results
  - ✓ Start with creating new init.c (sets initial fluid configurations, see PLUTO user manual Chapter 5)
    - ✓ Set initial conditions for density, pressure
      - ✓ Start out with basic model (uniform density, uniform pressure)
      - (sorta) Once basic models work, use n = 1 analytical solution for Lane-Emden equation to build more representative model.
      - (sorta) Solving the Poisson equation for gravitational potential will also need to be included so that the model does not evaporate (Body Forces; User manual S. 5.4)
  - Learn how to code in C!

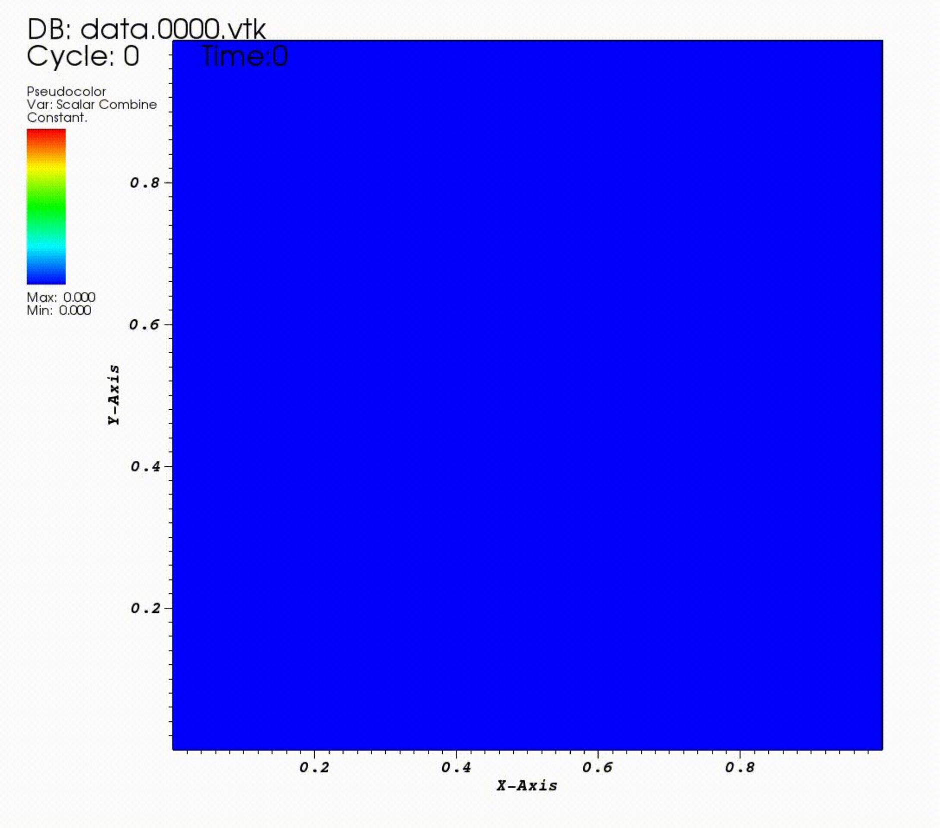
If these goals are achieved, modeling the magnetic field interior to the magnetar would be the next step in fully replicating Kuhn's computational model.

Monday / Tuesday

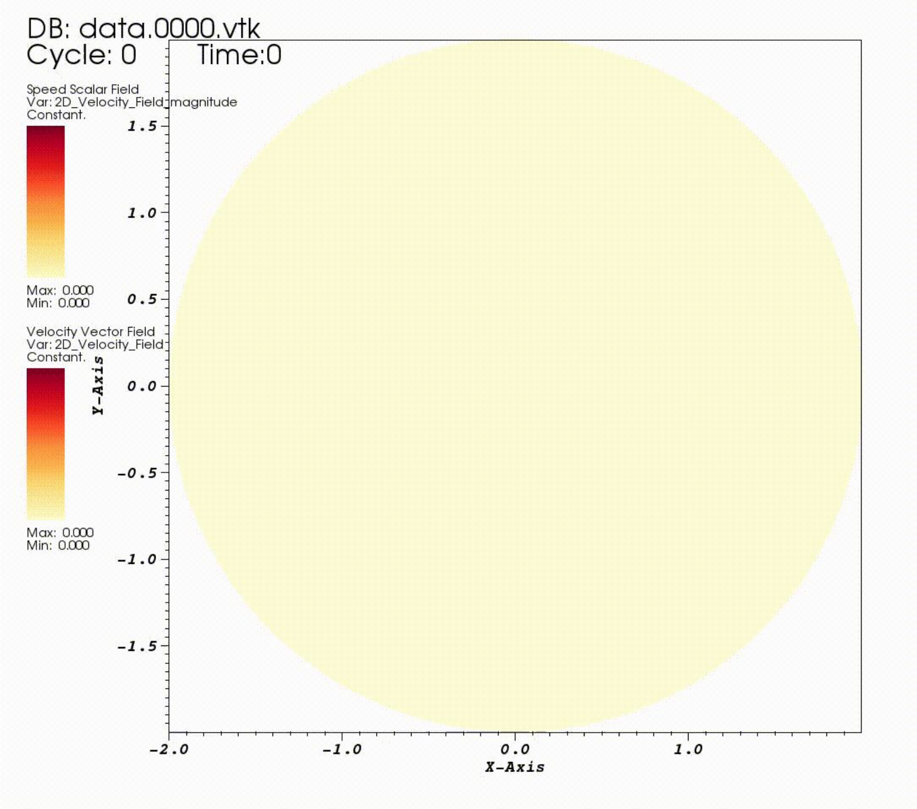
- Read literature on PDE solving / numerical methods to develop a working understanding of PLUTO is doing (*Numerical Methods*, Greenbaum and Chartier, *Computational Physics*, Newman) .
- Created “Weekly-Reports” Repository on GitHub
- `init.c, definitions.h, pluto.ini`
  - Created disk in cartesian coords. of uniform density with density ‘10’ computational units and pressure ‘30’ computational units surrounded by low density/ pressure region (ρ = 1, P = 1). Referenced PLUTO User Guide Ch. 5: Initial Conditions S. 5.1 (pg. 43).

Fluid Speed Scalar Graph

- Needed to reconfigure `pluto.ini` file to loop over region centered about origin.
- Density immediately disperses, expected as fluid flows from high to low pressure gradient.
    - No potential imposed yet.



- `init.c` reconfigured to graph in polar coordinates



Wednesday

- Created GitHub repository ‘Magnetar-PLUTO-files’ for work including `init.c, definitions.h, pluto.ini, make` files and folders for `.vtk` data test runs.
- Pressure, density functions from N = 1 polytrope added to code.
  - Create varied pressure and density throughout stellar disk *

$$\rho(r) = \rho_c \frac{sin(\pi r/R)R}{r\pi} \qquad r < R$$

$$P(r) = K\rho(r)^2$$

  - Gravitational Potential added*

Error in potential continuity, $4G\rho_c$ term should distribute to second term as well.

$$\phi_0 = 4G\rho_c(-\frac{R^2}{\pi}) - \frac{M}{4R\rho_c}$$

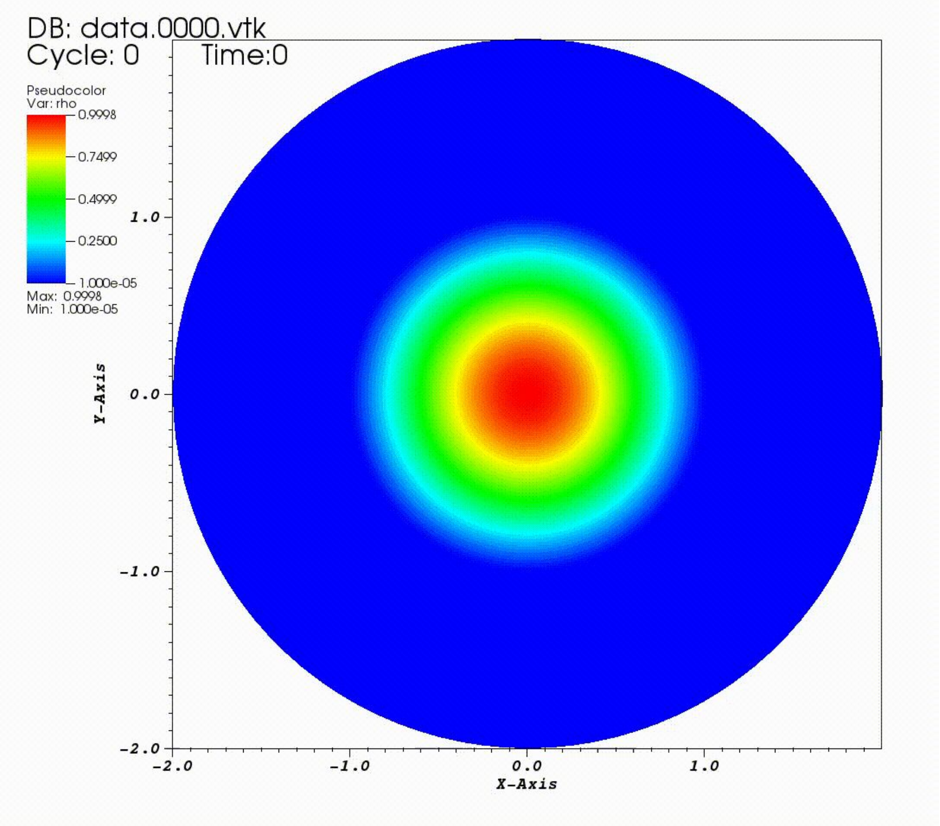
$$\phi_{inside} = 4G\rho_c(\frac{-R^3 sin(\pi r/R)}{\pi^2 r} - \frac{M}{4R\rho_c})$$

$$\phi_{outside} = -\frac{GM}{r}$$

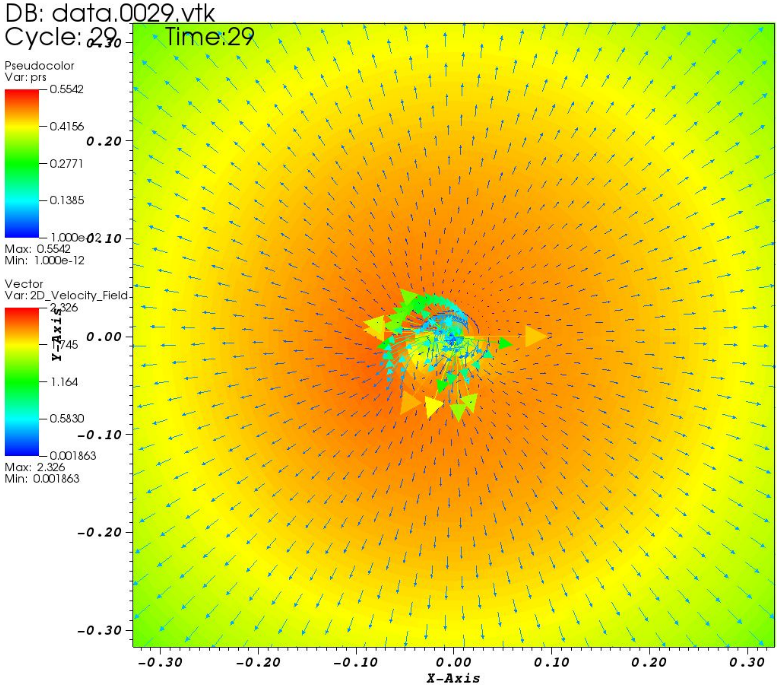
* Polytropic, potential equations implemented from Kuhn Thesis

Errors: Bound to happen!

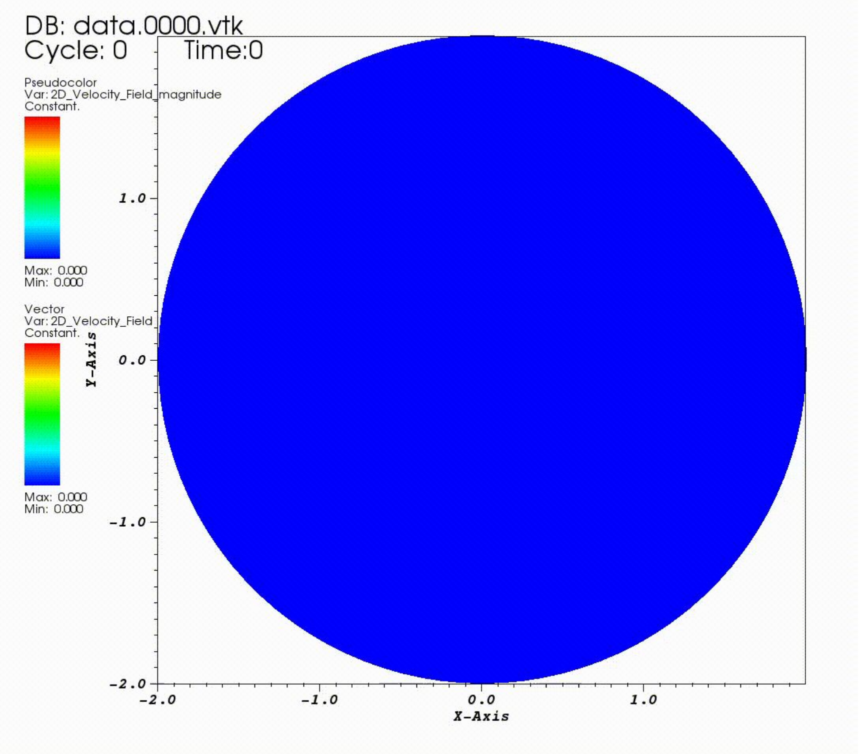
- Inaccuracies propagating in the region about r = 0.
  - Strong perturbations in density and velocity profile.
  - Likely an artifact of polar coordinate system.



Computational errors affecting model stability



Static image of velocity vector errors



Animation of velocity vectors causing propagation of shocks, mass outward.

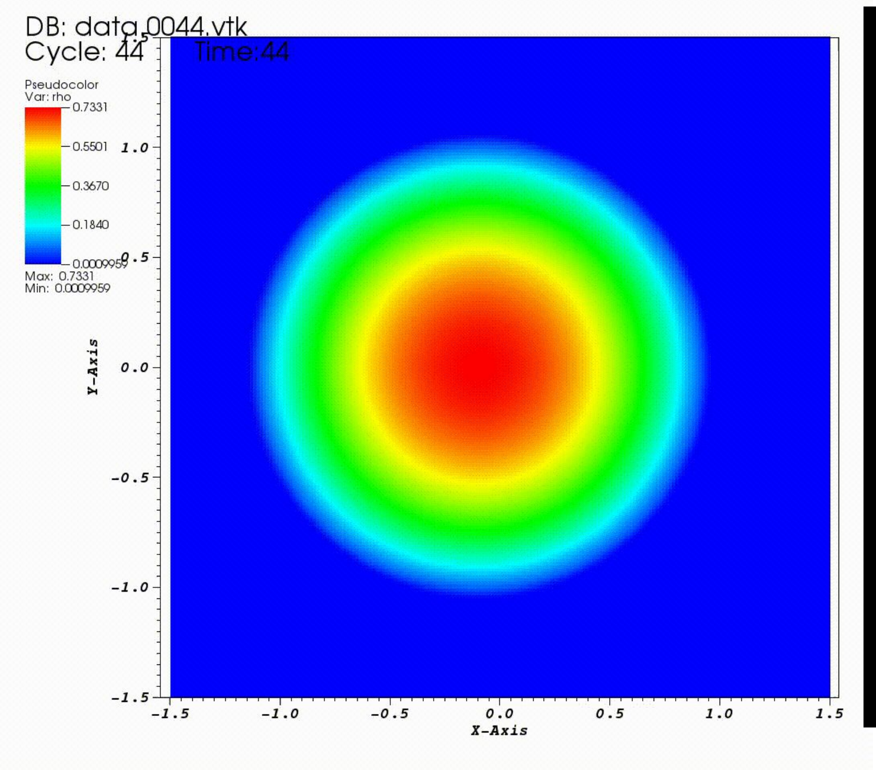
Thursday / Friday : Units (or a lack thereof?)

- PLUTO can be used in CGS units, however defaults to “non-dimensional (or code) units” (PLUTO User Guide S. 5.1.1, pg. 44).
  - It’s encouraged to scale quantities to non-dimensional units to underflows or overflows in numerical computation.
  - The following three fundamental units are defined (within `definitions.h` header file), from which all other units can be derived:
    - `UNIT_DENSITY` - reference density in gr/cm^2
    - `UNIT_LENGTH` - reference length in cm
    - `UNIT_VELOCITY` - reference velocity in cm/s^2
  - Example: redefine G:

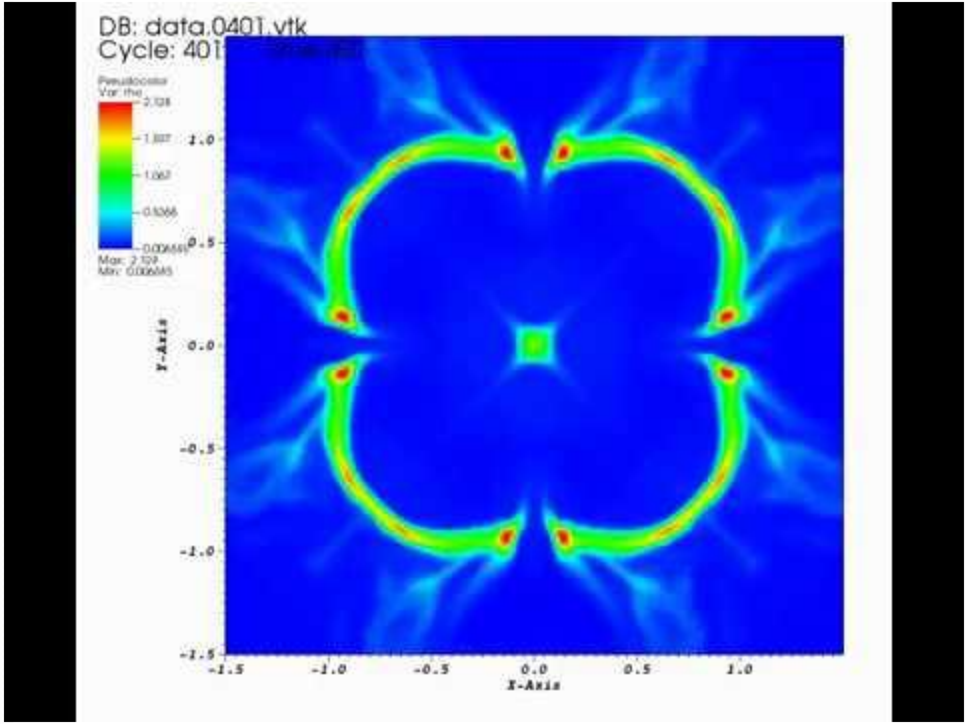
$$G_{unitless} = \frac{G_{cgs}}{v_0^2/\rho_0 \ell_0^2}$$

Saturday

- Despite various unit definitions, I kept running into issues with negative densities that abruptly develop as the simulation begins
  - The simulation often doesn’t get beyond one time step before crashing after reporting underflows in density.
- Calculated dimensionless values set aside to be able to test simulations
- Converted code to cartesian coordinates, vector issue at $r = 0$ disappeared, but new issue at $r = R = 1$ boundary.
  - Abrupt change in density along this region observed in simulations.
    - Suspected potential along the boundary may be to blame for behavior.



No potential



With potential

Questions and concerns I'd like to answer this week:

- Uncertain about unitless constants, curious how the issue of large magnitude calculations is solved elsewhere.
- Expansion tends to outpace counteracting potential, suggests pressure is not in equilibrium with potential, likely an issue of constants.
- Unsure whether model for potential is accurate, should first deriv. W.r.t r be continuous across the boundary r = R?
  - Out of curiosity, calculated deriv evaluated at r = R for φ_{inside} and $\varphi_{outside}$ and I did not find continuity.
- Equation of state for matter? PLUTO defaults to Ideal Gas, unsure whether this is most accurate (would an Isothermal EOS be a better fit?)

Goals for the Week:

- I intend to look into creating an `init.c` which dictates a model in spherical coordinates, this will introduce issues along $\Theta=\{0,\pi\}$ but may result in greater stability in model across r = R and the gravitational potential.
- Once stability is achieved, I intend to implement a model for the magnetic field, starting with a basic poloidal structure and then including toroidal components.
    - This would essentially complete the process of building Kuhn’s model she created for magnetars in PLUTO.