Research and educational opportunities of local models at the CCMC

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Research and education needs

Most models at CCMC developed for specific purpose

- Usually not many points of customization, for example one cannot (via web browser):
  - change strength of earth's dipole
  - spin up the sun or rotate in other direction
  - have three stars and one planet, etc.
  - fast 2d heliosphere with custom planets
  - vary atmospheric density, composition, rotation
- No 1d or 2d runs, simple tests, examples
- Not much room for exploration
- Local models can fill some above gaps

Local plasma model

- Solves magnetohydrodynamic (MHD), hybrid or full kinetic plasma equations
  - describes plasma on large (fluid), medium (ions) and small (electrons) temporal & spatial scales
- Little or no application specific functionality
  - no ionosphere, flux rope, magnetogram, etc.
  - periodic grid or simple boundary conditions
- Added to CCMC in 2015

Local models at CCMC

- 3 models have results, but not yet runnable
  - full kinetic description of plasma (particle-in-cell method)
  - PIC-Hesse, P3D, VPIC
  - 2d magnetic reconnection
  - 5 runs total
  - arbitrary plotting of bulk plasma and field data
  - distribution function plots from predermined locations
- 1 model runnable

Local models at CCMC

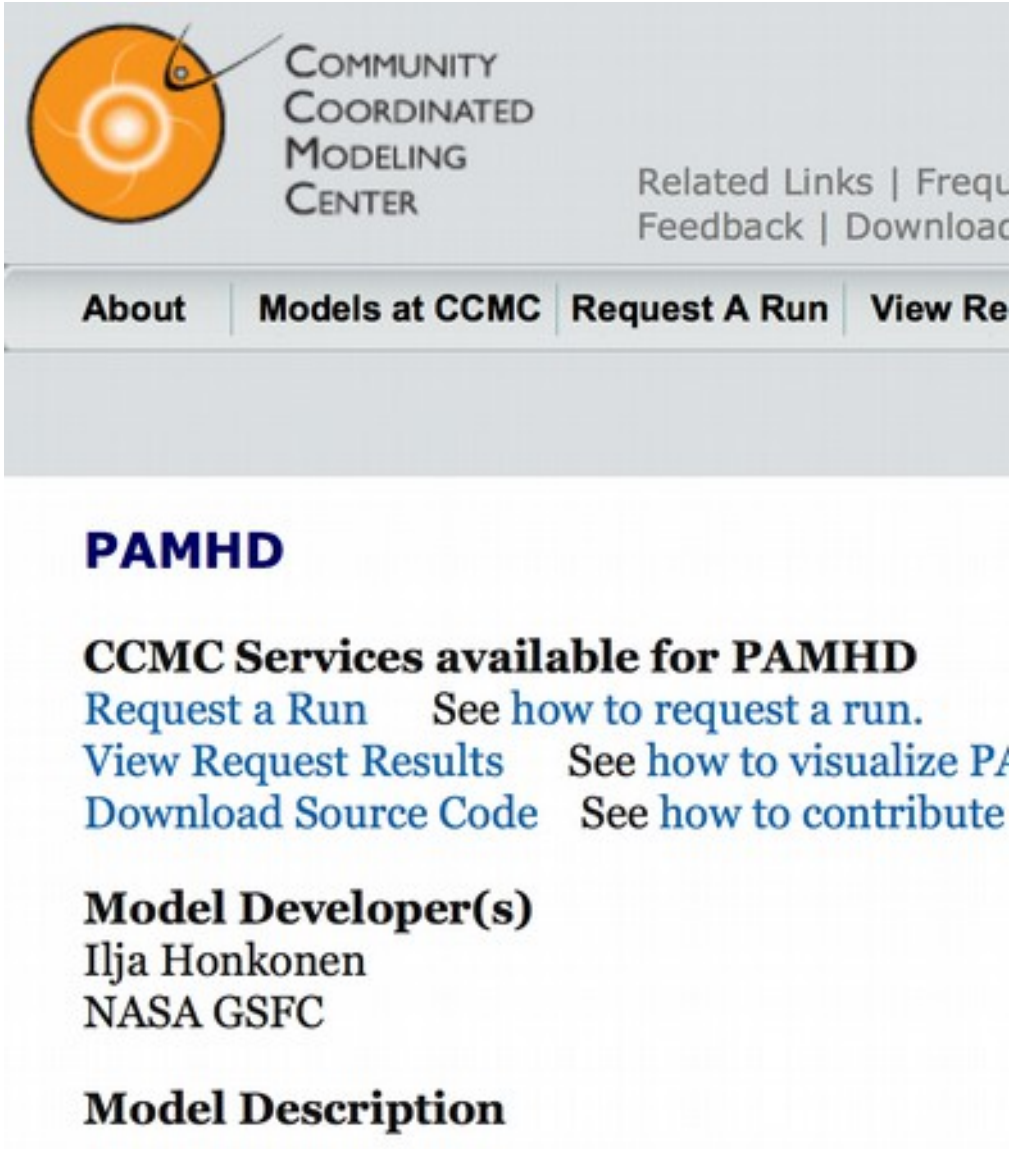
- 3 models have results, but not yet runnable
- 1 model runnable via Runs-on-Request
  - ccmc.gsfc.nasa.gov/models/modelinfo.php?model=PAMHD
  - MHD part of particle-assisted MHD (PAMHD)
    - hybrid particle-in-cell part in testing
  - 1d, 2d, 3d, periodic grid or simple boundary conditions
  - results so far include reconnection, shock tube, blast wave, bow shock, advection, Kelvin-Helmholtz, solar wind signal attenuation (relevant to ULF challenge)

Particle-Assisted MHD

- Available at github.com/nasailja/pamhd
  - license of MHD part GPLv3, others mostly BSD(3)
- Dynamic run submission page using javascript
  - add/remove initial/boundary conditions client-side
  - based on index.html in github repository
- Run composed from choice of:
  - any number of initial and boundary volumes
  - box and sphere geometries
  - value and copy boundaries
  - time & space dependent mathematical expressions

Particle-Assisted MHD

Demo of requesting a PAMHD run from CCMC: How to request a PAMHD run on CCMC, hires.mp4



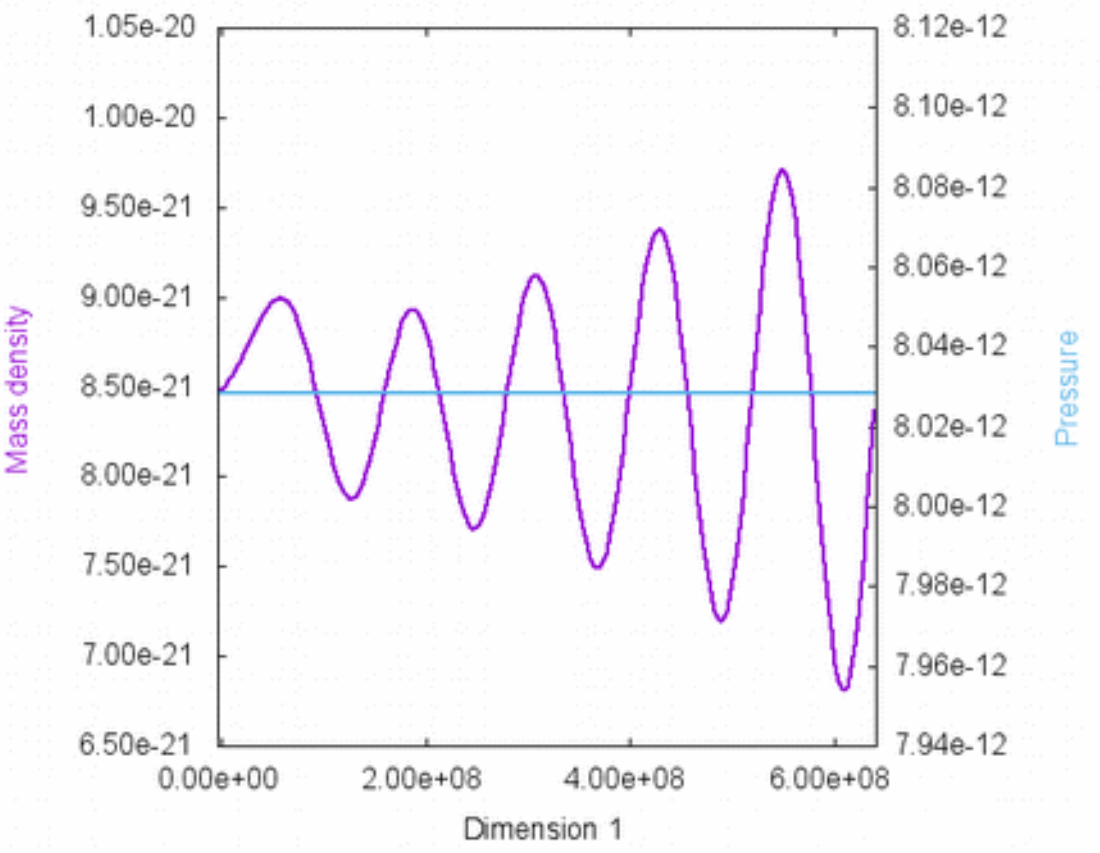
Educational opportunities of local models (in addition to usual CCMC advantages)

- For Runs-on-Request (RoR) beginners
  - study simple(st) plasma systems in 1d, 2d, 3d
    - advection, reconnection, instabilities, waves (CME rarefaction), discontinuities, shocks
    - study effects of initial / boundary values
  - plot, understand and reproduce results from plasma physics lectures, books, papers, etc.

Educational opportunities of local models

Demo of solar wind run:
solar_wind.gif

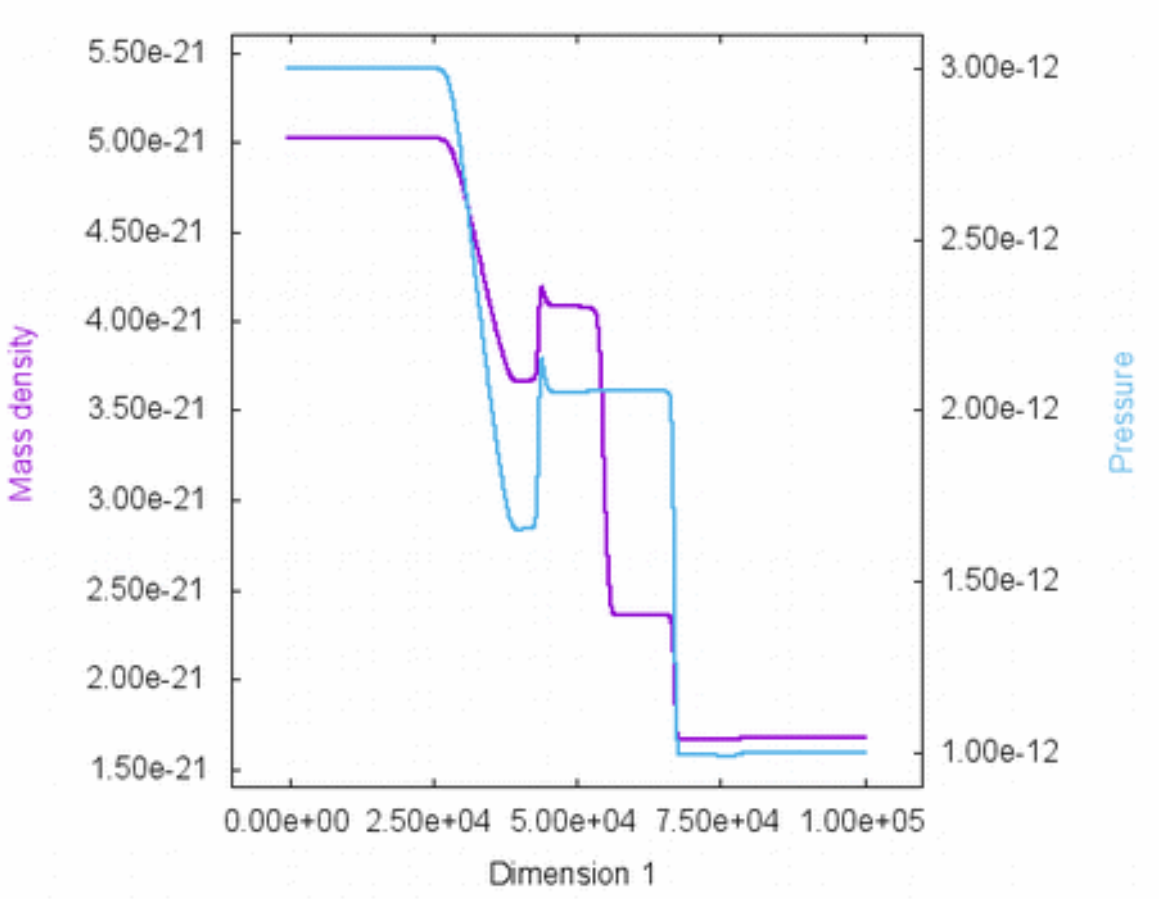
- 1d box with uniform density, pressure, B
- Value boundary on right, copy boundary on left
  - number density: 5e6 * (1 + 0.2 * sin(0.01 * pi * t))



Educational opportunities of local models

Demo of shock tube run:
shock_tube.gif

- 1d box divided into initial condition of two states
- Value boundaries at ends of tube



Educational opportunities of local models (since PAMHD is free & open source)

- For beginning model developers
  - see how things are / can be done in practice
  - from Jacobian in MHD paper to implementation
  - use of existing software (athena, boost, dccrg, eigen, muparserx, zoltan, ...)
- Point and click development in browser via github (How to contribute to PAMHD.mp4)
  - use, study, modify existing code
  - create new test configurations
  - submit changes for comments/review/inclusion

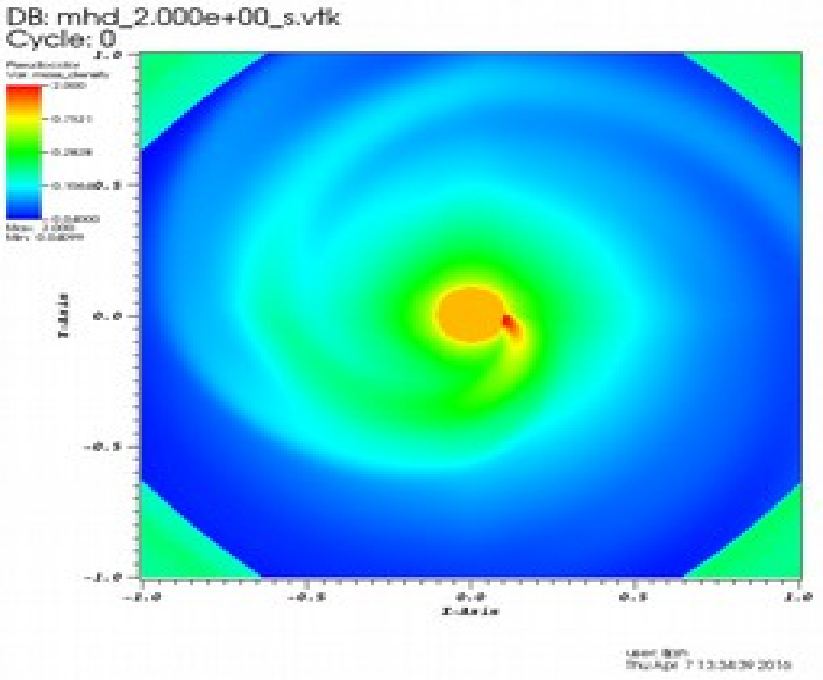
Research opportunities of local models

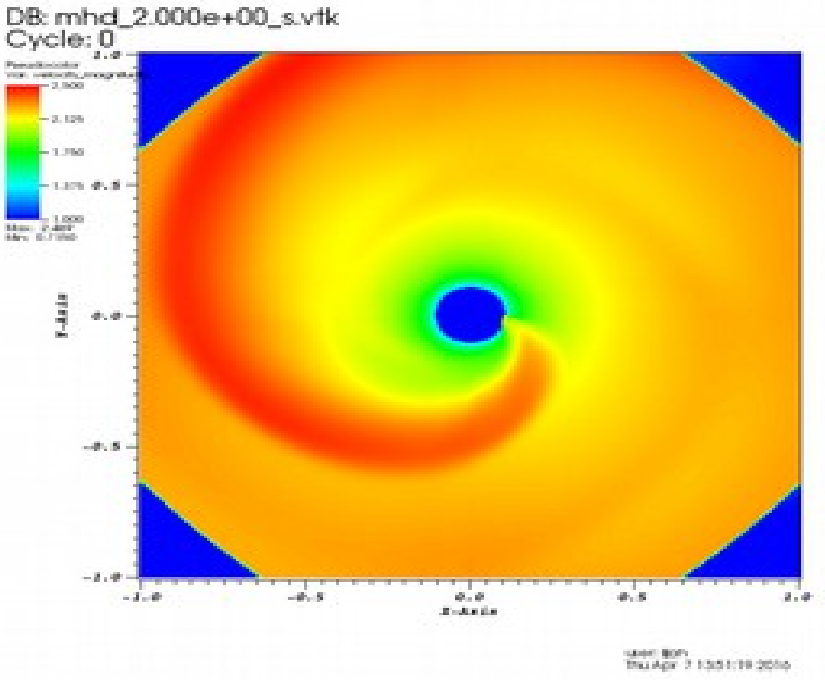
- For RoR pros
  - extend existing runs with new boundaries, dimensions
  - investigate hypotheses from observations and global models
    - create simplified cases, how simple is good enough?
    - where/why do global models fail, what should work?
  - explore new configurations
  - suggest / modify existing and/or develop new boundary conditions
  - many astrophysical possibilities

Research opportunities of local models

Demo of 2d heliosphere run: heliosphere.gif

- 2d box with initially uniform density, B no V
- Box copy boundaries at edges of simulation volume, spherical value boundary at center:
  - density: fmod(abs(fmod(atan2(r[1],r[0]) + 2*pi, 2*pi) - 4*pi*t), 2*pi) < pi/8 ? 2 : 1
  - velocity: radial outflow * above expression





Research opportunities of local models

- For RoR pros
- For pro developers
  - advanced C++ programming (gmd-8-473-2015)
  - new simulation variable: +2 lines of code (LOC)
  - update above variable between processes: +2 LOC
  - couple different variables: +0-10 LOC
- high performance computing (j.cpc.2012.12.017)
  - parts tested up to 64k processes and 98k cores
  - CCMC testing NASA Pleiades (>200k cores) for RoR
- algorithms TODO: adaptive mesh refinement, constrained transport, self-gravity, better accuracy, spherical geometry, special/general relativity, etc.