AstroGK: Astrophysical Gyrokinetics Code

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Gyrokinetics

AstroGK is a continuum $\delta f$ gyrokinetics code

Vlasov-Landau-Maxwell $\rightarrow$ Gyrokinetic-Maxwell

Gyrokinetic Ordering

Existence of mean magnetic field allows us to reduce phase-space dimension from 6 to 5

$$(x, y, z, v_x, v_y, v_z) \rightarrow (x, y, z, v_\perp, v_\parallel)$$

Throw away gyrophase $\theta$ dependence
Gyrokinetic Equation

\[
\begin{align*}
\frac{\partial h}{\partial t} + \frac{\partial h}{\partial z} + \frac{1}{B_0} \left\{ \langle \chi \rangle_R, h \right\} + L(h) &= \frac{q f_0}{T_0} \frac{\partial \langle \chi \rangle_R}{\partial t} + C(h)
\end{align*}
\]

• Field \( \chi \) is obtained by taking velocity moment of \( h \) (Maxwell's eqns). We use a Green's function technique to solve the field equation, thus field is given.

• The Poisson bracket term is nonlinear.

• The collision operator \( C \) includes second order derivatives w.r.t. velocity coordinates.

5D nonlinear differential eqn
Algorithm

\[ \frac{\partial h}{\partial t} + \frac{\partial h}{\partial z} + \frac{1}{B_0} \langle \langle \chi \rangle_R, h \rangle \rangle + L(h) = \frac{q f_0}{T_0} \frac{\partial \langle \langle \chi \rangle_R \rangle}{\partial t} + C(h) \]

- Implicit except nonlinear term
- Compact finite difference in \( z \)
- Inversion of bi-diagonal \( N_z \) size matrix

- Fourier spectral method for nonlinear Poisson bracket
- FFTW2

- Finite difference and integrals for velocity derivatives in \( C \)

- Field solver: Inversion of dense \( N_z \) size matrix
  - Matrix is fixed for given \( \Delta t \)
Parallelization Scheme

\[ h = h(k_x, k_y, z, \lambda, E, s) \]

- Distribute distribution function data on processors
- Number of grids varies depending on problems
  - 2D in configuration space \((N_z\text{ ignorable})\)
  - Linear problem \((N_{kx}, N_{ky}\text{ ignorable})\)
- Number of grids in each dimension is not very large
  - Usually < 256
- Combined grid is used to parallelize
- Order of combination depends on user input

\[ \frac{N_{k_x} N_{k_y} N_{\lambda} N_E N_s}{N_p} \]
Bottlenecks

- Data redistribution

FFT \leftrightarrow \text{Collisions (FD in } \lambda) \leftrightarrow \text{Collisions (FD in } E)\

OpenMP? SMEM?

- FFT
Performance Scaling

AstroGK Weak Scaling Performance
Kraken, Cray XT5

--- Ideal
○ Measured

AstroGK Strong Scaling Performance
Kraken, Cray XT5

--- Ideal (48)
--- Ideal (384)
○ Time per step