AstroGK: Astrophysical Gyrokinetics Code

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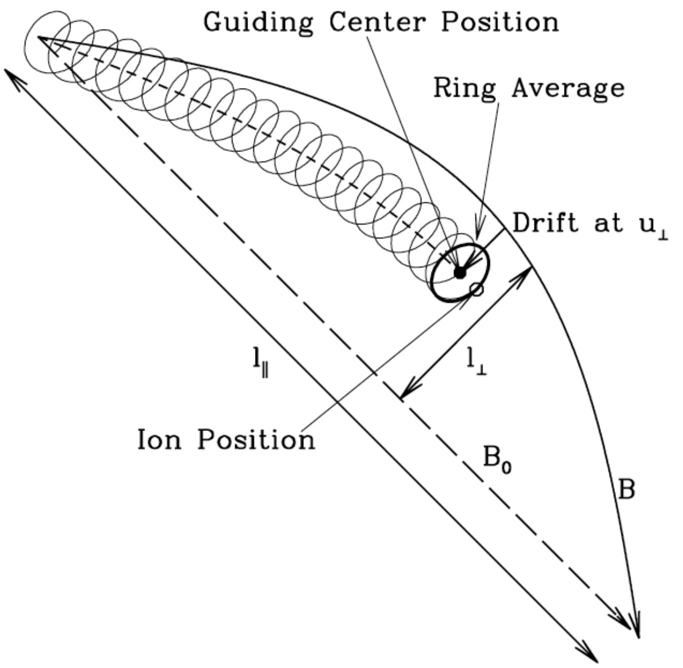
Gyrokinetics

AstroGK is a continuum *δf* 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 θ dependence

Gryokinetic Equation

$$\frac{\partial h}{\partial t}+\frac{\partial h}{\partial z}+\frac{1}{B_0}\{\langle\chi\rangle_{\boldsymbol{R}},h\}+L(h)=\frac{q f_0}{T_0}\frac{\partial\langle\chi\rangle_{\boldsymbol{R}}}{\partial t}+C(h)$$

- Field χ 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

$$\frac{\partial h}{\partial t}+\frac{\partial h}{\partial z}+\frac{1}{B_0}\{\langle\chi\rangle_{\boldsymbol{R}},\boldsymbol{h}\}+L(\boldsymbol{h})=\frac{q f_0}{T_0}\frac{\partial\langle\chi\rangle_{\boldsymbol{R}}}{\partial t}+C(h)$$

- 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 Δt

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 ignorable)
- Linear problem (N_{kx}, N_{ky} ignorable)

•Number of grids in each dimension is not very large
- Usually < 256

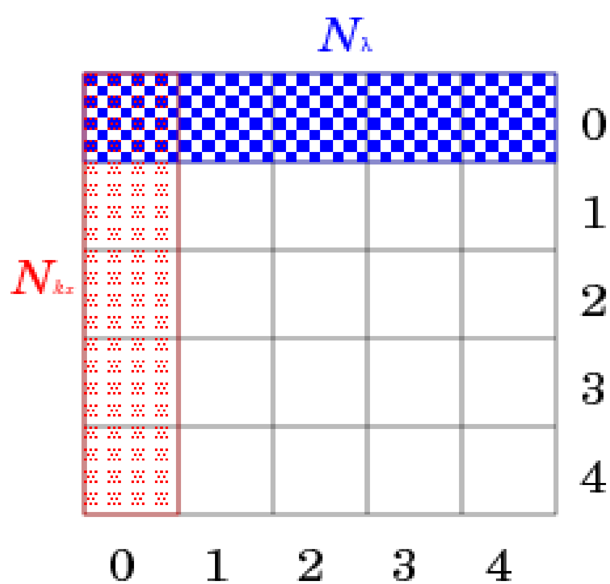
•Combined grid is used to parallelize
•Order of combination depends on user input

$$\frac{N_{k_x} N_{k_y} N_\lambda N_E N_s}{N_p}$$

Bottlenecks

•Data redistribtion

FFT ⟷ Collisions (FD in λ) ⟷ Collisions (FD in *E*)



OpenMP? SMEM?

•FFT

Performance Scaling