Hybrid Kinetic MHD and Full Orbits in NIMROD

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Overview of Past Work

- implement hot particle pressure tensor in the momentum equation:

$$\rho\left(\frac{\partial \mathbf{U}}{\partial t}+\mathbf{U}\cdot\nabla\mathbf{U}\right)=\mathbf{J}\times\mathbf{B}-\nabla\cdot\underline{\mathbf{p}}_b-\nabla\cdot\underline{\mathbf{p}}_h$$

  the subscripts b, h denote the bulk plasma and hot particles

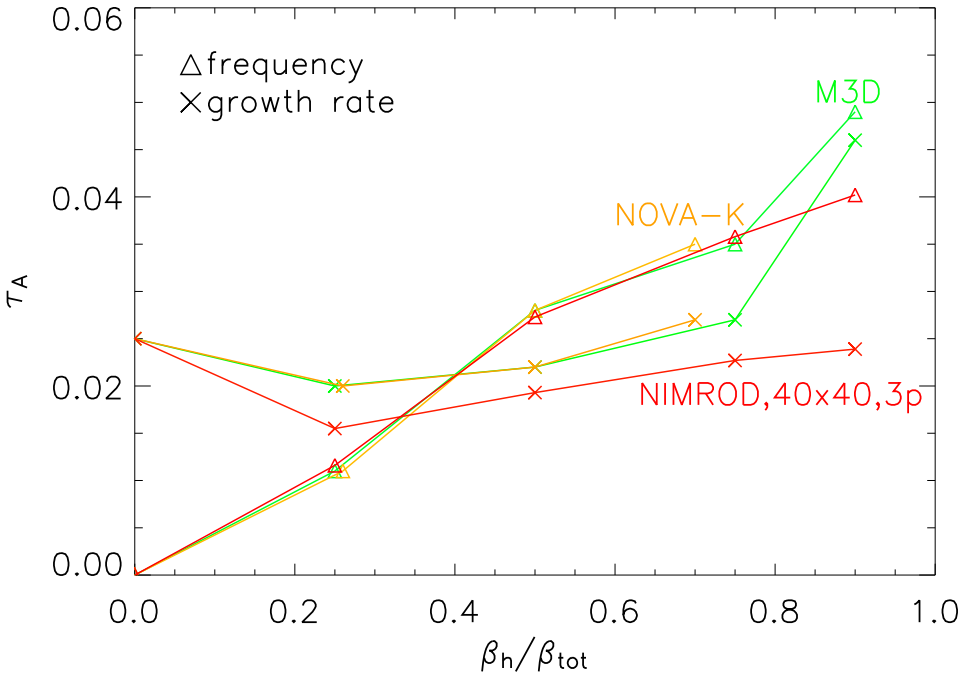
- assume CGL-like form $\delta\underline{\mathbf{p}}_h=\begin{pmatrix} p_\perp & 0 & 0\\ 0 & p_\perp & 0\\ 0 & 0 & p_\parallel\end{pmatrix}$

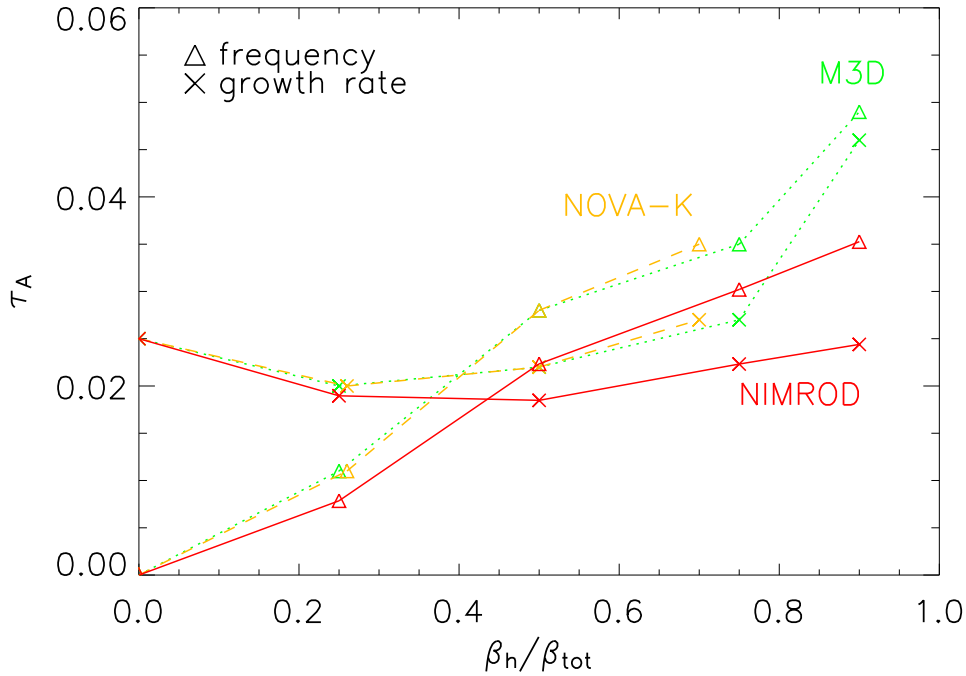
- evaluate pressure moment using δf PIC method

$$\begin{aligned}\delta p(\mathbf{x}) &= \int m(v-V_h)^2\,\delta f(\mathbf{x},\mathbf{v})\,d^3v\\ &= \sum_{i=1}^{N} m(v_i-V_h)^2\,g_0 w_i\,\delta^3(x-x_i)\end{aligned}$$

BUG in Drift Kinetic Benchmark with M3D

- discovered that I was not taking **SQRT** in calculating $|B| \rightarrow$ **YIKES!!**





- downward shift of real frequency, marginal effect on growth rate
- explore source of discrepency - **?**using ψ_p not P_ζ**?**

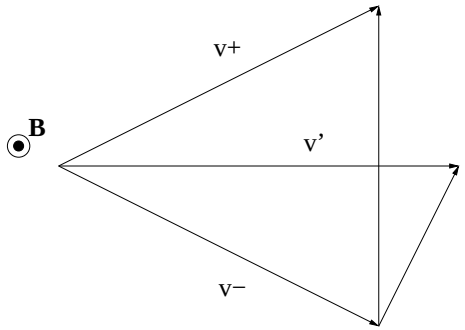
PSI Center Kinetic Group

- **Objective:** develop the capability to model full kinetic minority species in NIMROD
- The Plan
  - implement full kinetic orbits for particles - Boris Push
  - test different coupling schemes (**J** vs. **P**)
  - improve timestepping → orbit averaging
  - implement collisions with background[a]
  - implement multiple 'species' e.g. some full kinetic particles some drift
  - explore issues concerning open boundary conditions[b]
  - explore running fluid electrons and kinetic ions

[a] Y. Chen and R. B. White,'Collisional δf method', *Physics of Plasmas* **4** 3591 (1997)
[b] ibid

Description of the Boris Algorithm[a]

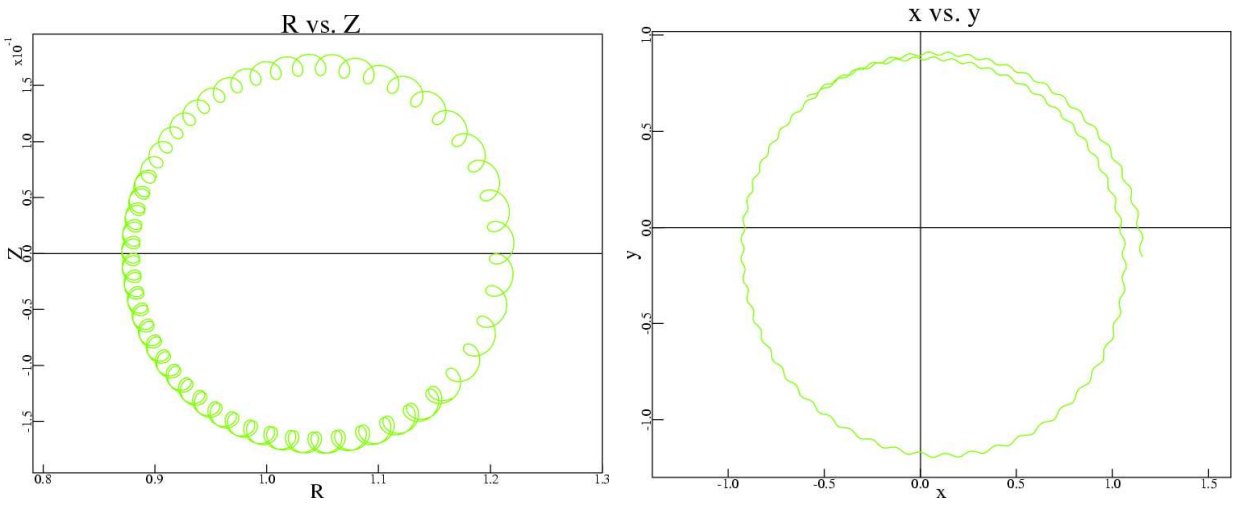
- Boris push utilizes leap frog time centering
- half step push of electric field $\mathbf{v}^- = \mathbf{v}_{t-\Delta t/2} + \frac{q\mathbf{E}}{m}\frac{\Delta t}{2}$
- increment $\mathbf{v}^-$ to $\mathbf{v}' = \mathbf{v}^- + \mathbf{v}^- \times \vec{\omega}_c \frac{\Delta t}{2}$ where $\vec{\omega}_c = \frac{q\mathbf{B}}{m}$



- rotate $\mathbf{v}^-$ to $\mathbf{v}^+ = \mathbf{v}^- + \mathbf{v}' \times s\vec{\omega}_c$ where $s = \frac{\Delta t}{1+\omega_c^2 \frac{\Delta t^2}{4}}$ s.t. $|\mathbf{v}^+| = |\mathbf{v}^-|$
- remainder of half step push of electric field $\mathbf{v}_{t+\Delta t/2} = \mathbf{v}^+ + \frac{q\mathbf{E}}{m}\frac{\Delta t}{2}$

Ion Orbits Nontrivial in ICC Devices

full orbits has marginal consequences for overall trajectory in tokamaks



nontrivial orbits in ICCs