Efficient Hybrid Methods for the Simulation of Plasmas with Coulomb Collisions

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Introduction: \[ Kn \equiv \frac{\lambda_{\text{mfp}}}{L}, \frac{t}{\tau} \lesssim 1 \]
Fluid Equations

$f = M + k$

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\[
f = M + k
\]

\[
\frac{Dk}{Dt} = C[k]
\]

Fluid Equations
Collisions: Binary Coulomb

- Deterministic
- Expensive
Collisions: Binary Coulomb


- Stochastic
- Inexpensive
Collisions: Binary Electron-Electron Test Case

\[ \frac{(T_z - T_\perp)}{T_r} : O(\Delta t^r) \]

Nanbu

Takizuka & Abe

Collisions: Binary Electron-Electron Test Case

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\[ r : O(\Delta t^{1/2}) \]

- Methods comparable
- Accuracy: \( O(\Delta t^{1/2}) \)

Introduction: \( Kn \equiv \frac{\lambda_{\text{mfp}}}{L}, t/\tau \lesssim 1 \)

\[ f = M + k \]

\[ \frac{Dk}{Dt} = C[k] \]

Fluid Equations
Hybrid Method: Decomposition & (De)Thermalization

Fluid Equations

\[- C[f, k] - S_{de} + S_{th}\]

- Conserves Moments
- (De)Thermalization freedom
- Accuracy & Efficiency optimization

\[
\frac{Dk}{Dt} = C[f, k] + S_{de} - S_{th}
\]
Hybrid Method: Decomposition & (De)Thermalization

- $\theta$ determines probability of (De)Thermalization
- $P(\theta)$ is tunable (but constrained by physics).
- Methods used in neutral kinetics
Hybrid Method: Decomposition & (De)Thermalization

\[ \Delta M = M(t + \Delta t) - M_C(t) \]

- Particle passive-scalars
- Entropy based thermalization

\[ \Delta M: \text{Lagrangian change} \]
- Kinetic ‘Forcing’ dethermalizing

1. Ricketson, Dimits, Rosin, Cohen, Caflisch, *Work in Progress, 2011*
Introduction: $Kn \equiv \lambda_{mfp}/L, t/\tau \lesssim 1$

Fluid Equations

\[ \frac{Dk}{Dt} = C[k] \]

Fluid Equations
Hybrid Test Case: Bump-On-Tail

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Saving ~ factor 2

Hybrid Test Case: Inverse-Bremsstrahlung Heating

- Oscillating laser electric field
- Collisional ion-electron heating

1. Rosin, Dimits, Cohen, Caflisch, *Work in Progress, 2011*
Hybrid Test Case: Inverse-Bremsstrahlung Heating

- Oscillating laser field
- Collisional heating

Saving $\sim$ factor 8

Hybrid Test Case: Electric Sheath

\[ \frac{\phi}{eT} \]

\[ \frac{x}{\lambda_D} \]

Density

\[ f(v_{\parallel}, v_{\perp}) \]

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1. Dimits, Rosin, Cohen, Caflisch, 2011, *Work in Progress*
Hybrid Test Case: Electric Sheath

Saving ~ factor 10

1. Dimits, Rosin, Cohen, Caflisch, 2011, Work in Progress
Conclusions and Future Work

Conclusions

- Hybrid scheme is ~ 1-10 times more efficient
- Effectiveness is problem dependent
- Optimization between accuracy and efficiency
- Multiple (de)thermalization criteria
- Applications: Edge plasma, lasers, diodes

Future Work

- Efficiency/Accuracy parameter scans for lasers/sheath
- Determine case’s optimal (de)thermalization criteria
- Combine with Langevin model for particle-grid collisions
- Dynamically combine multiple problem sets
- Extend hybrid method to transport equations

Further Progress at APS DPP (Nov)