Efficient Hybrid Methods for the Simulation of Plasmas with Coulomb Collisions

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UCLA & LLNL

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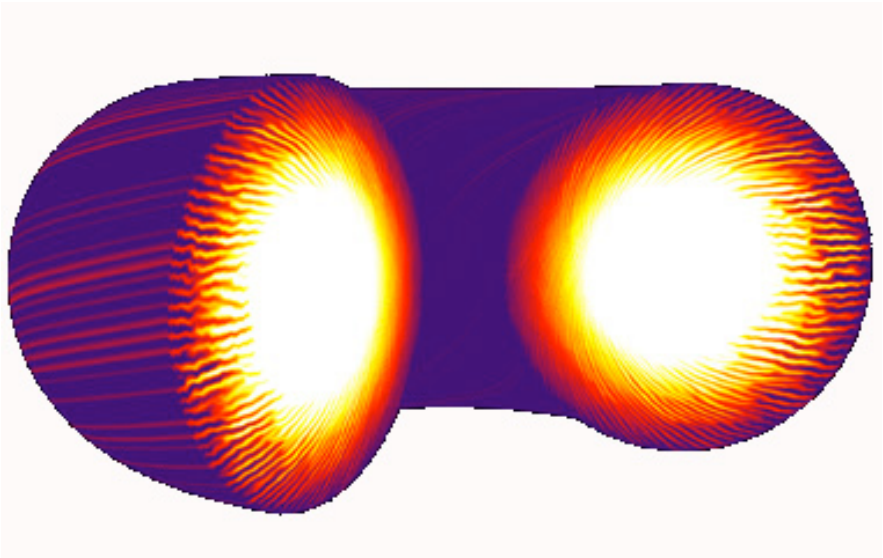
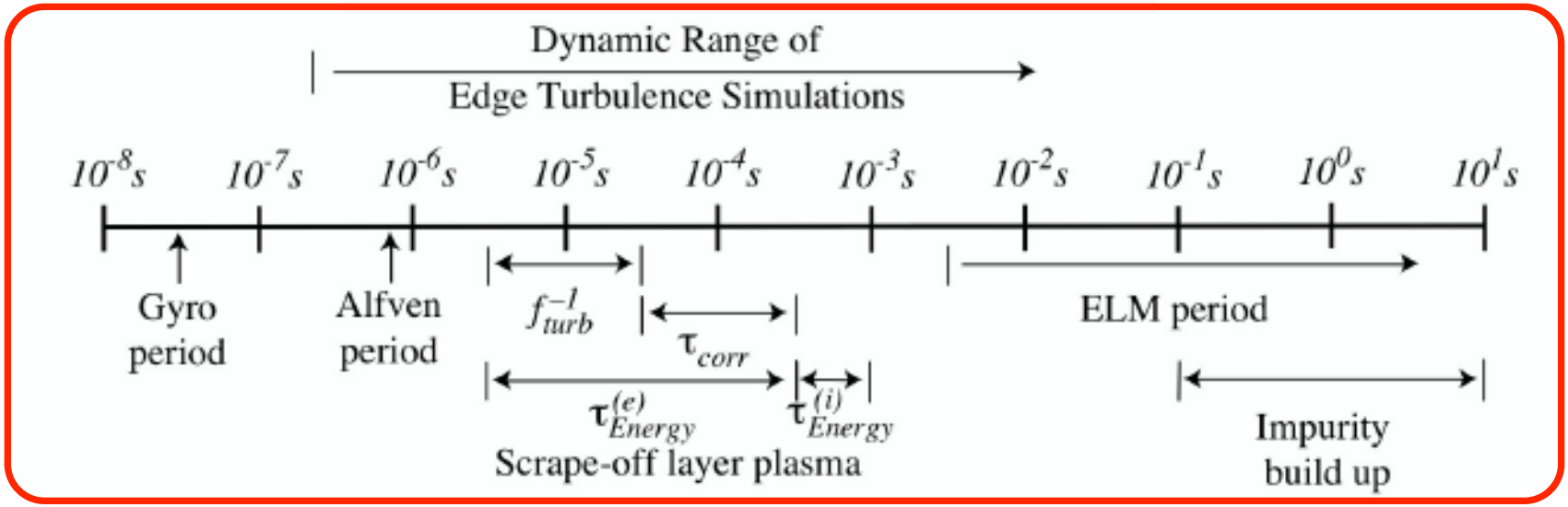
UCLA

Fusion Energy Sciences

Introduction: $Kn \equiv \lambda_{\mathrm{mfp}}/L, t/\tau \lesssim 1$





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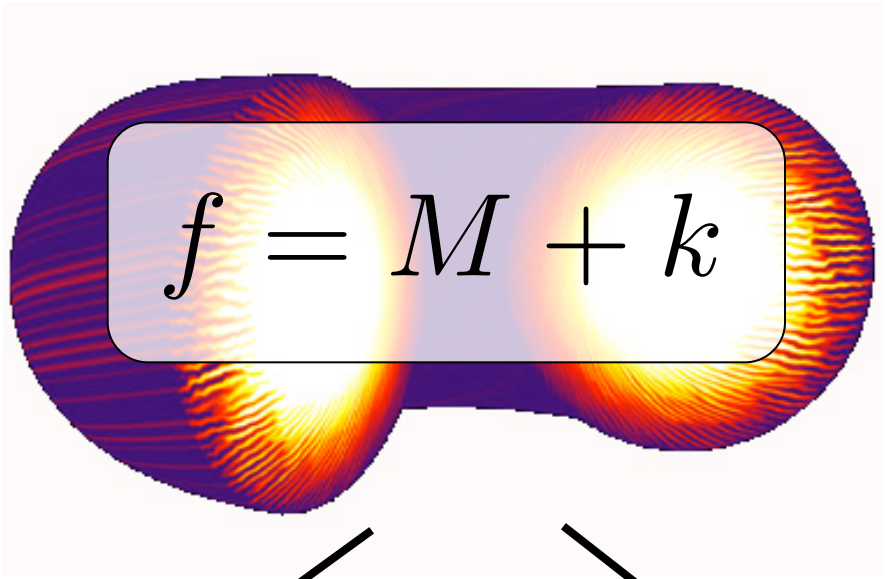

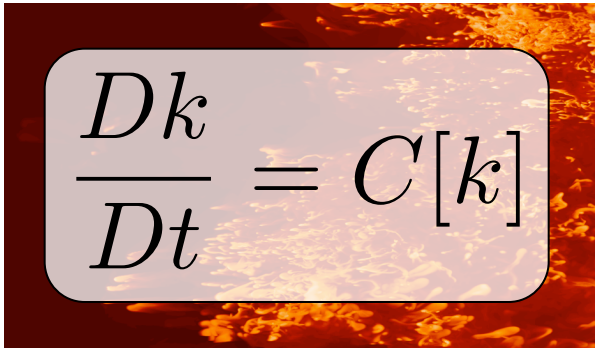

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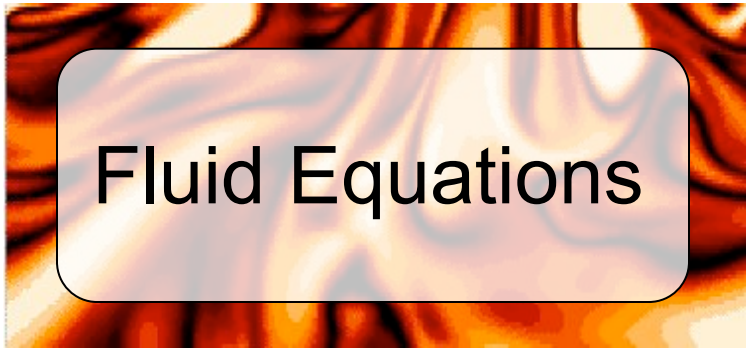

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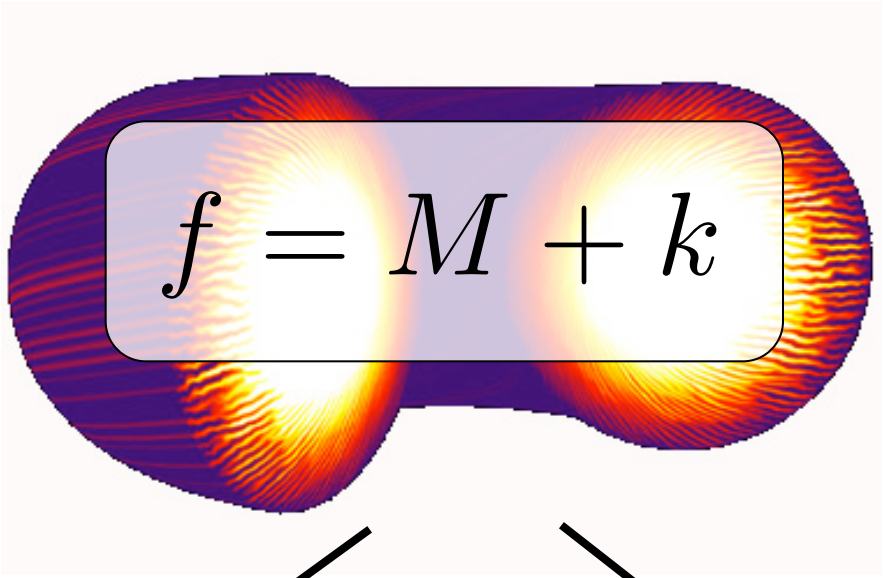
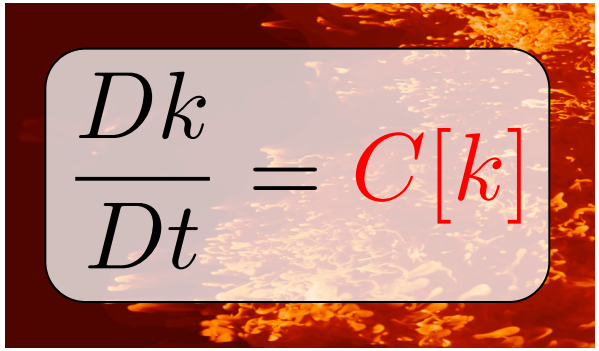
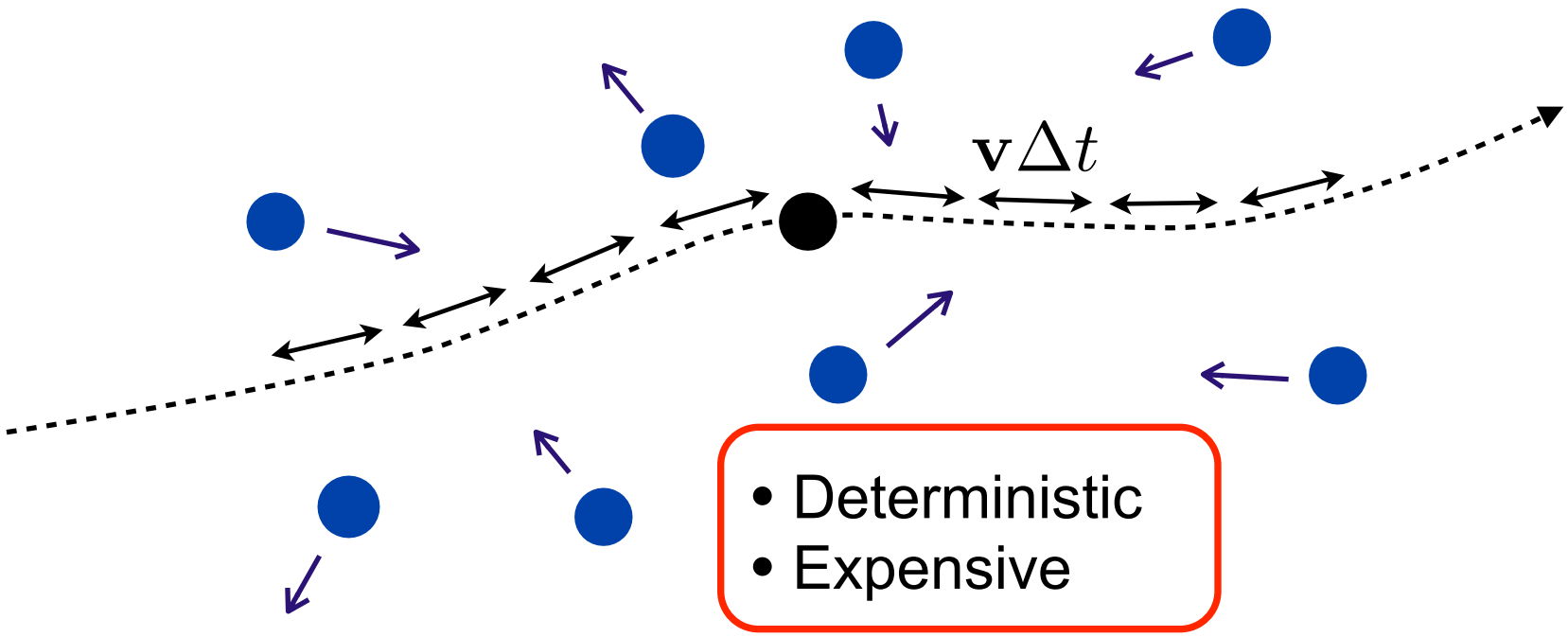


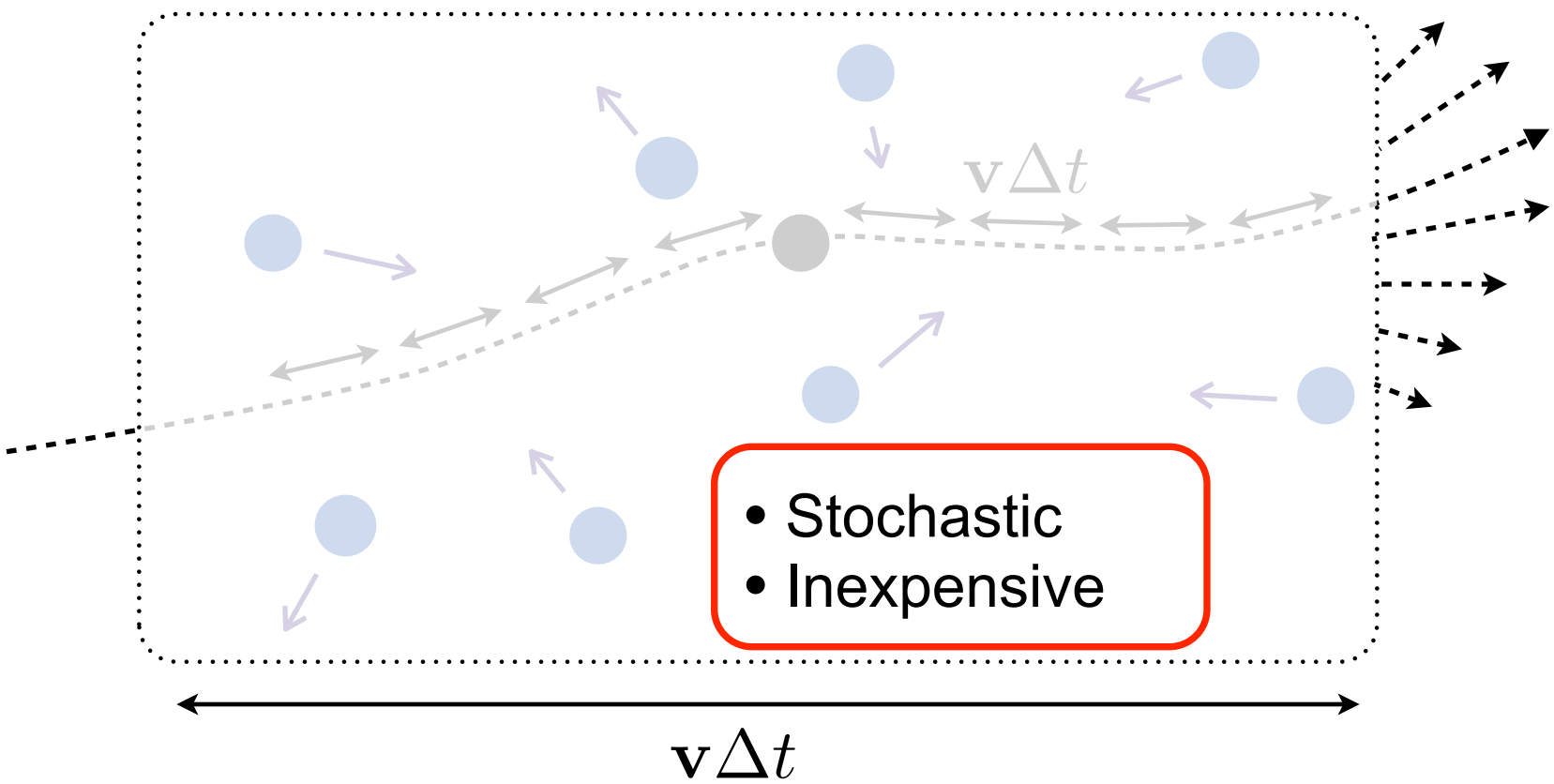


Collisions: Binary Coulomb



- Deterministic
- Expensive

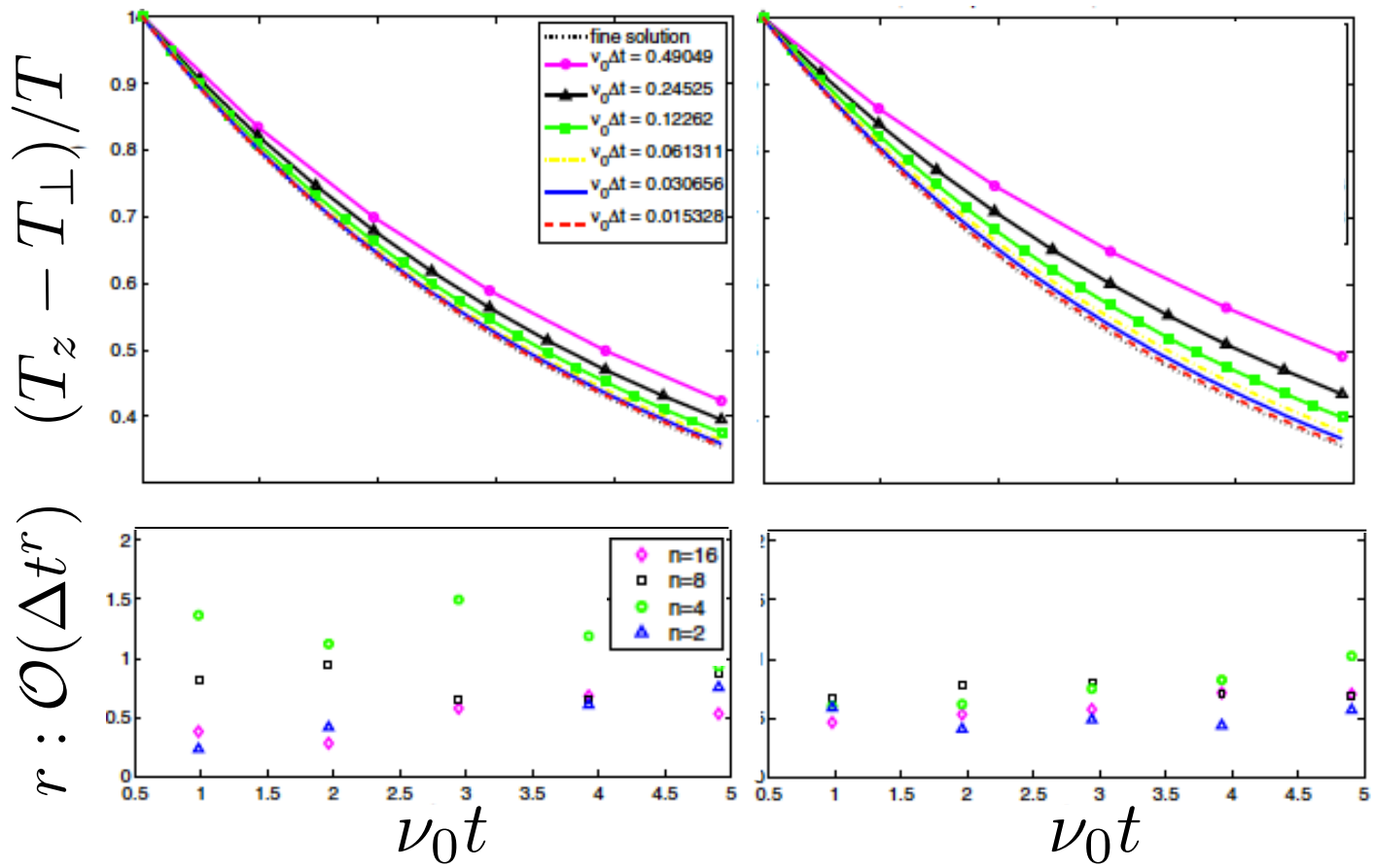
Collisions: Binary Coulomb



1. Takizuka, Abe, 1977, *J. Comp. Phys*, 25, 205
2. Nanbu, 1997, *Phys. Rev. E.*. 55, 4642

Collisions: Binary Electron-Electron Test Case

Nanbu | Takizuka & Abe



1. Wang, Lin, Caflisch, Cohen, Dimits, 2008, *J. Comp. Phys,,* 227, 4308
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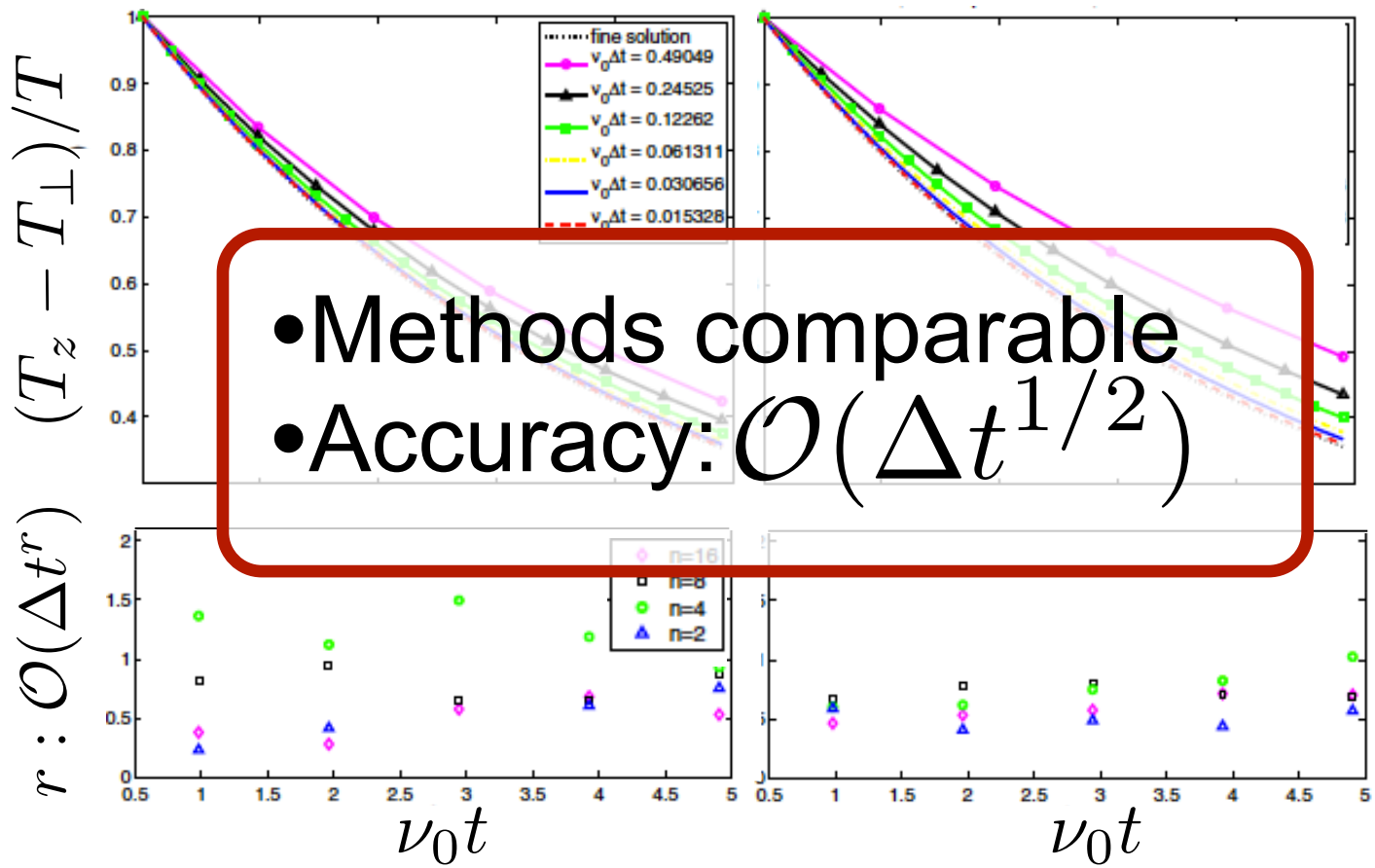

- Methods comparable
- Accuracy: $\mathcal{O}(\Delta t^{1/2})$

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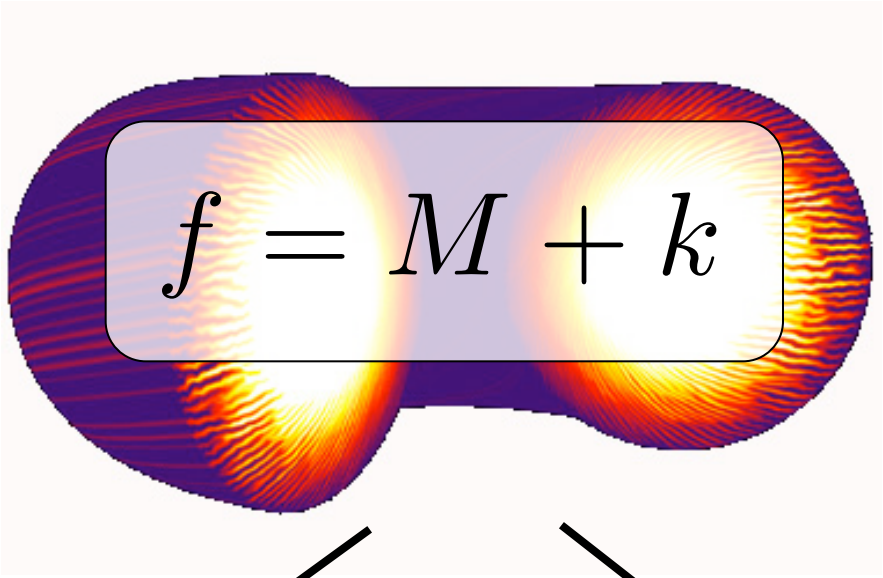
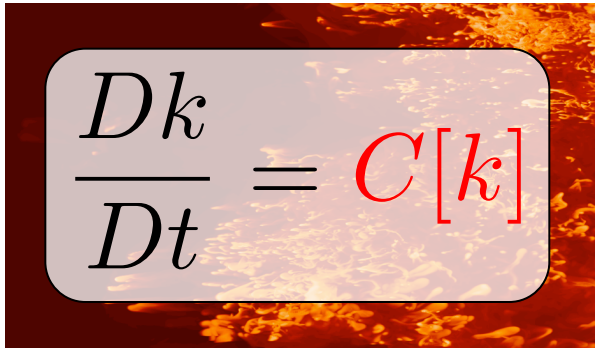




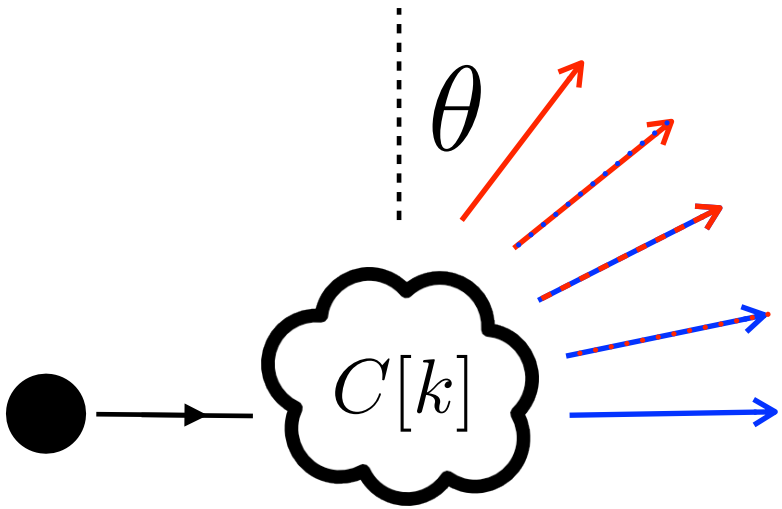
Hybrid Method: Decomposition & (De)Thermalization

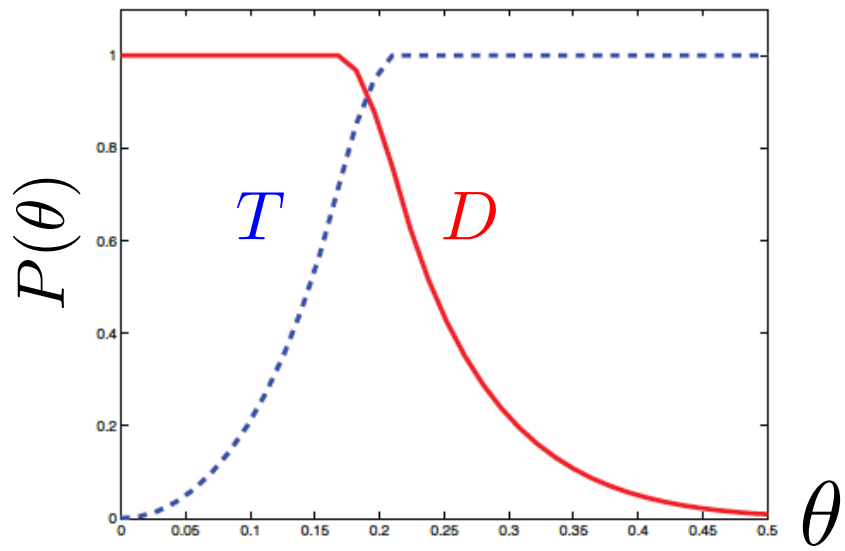
Fluid Equations $-\overline{C[f,k]} - \overline{S_{\mathrm{de}}} + \overline{S_{\mathrm{th}}}$

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

$$\frac{Dk}{Dt} = C[f,k] + S_{\mathrm{de}} - S_{\mathrm{th}}$$

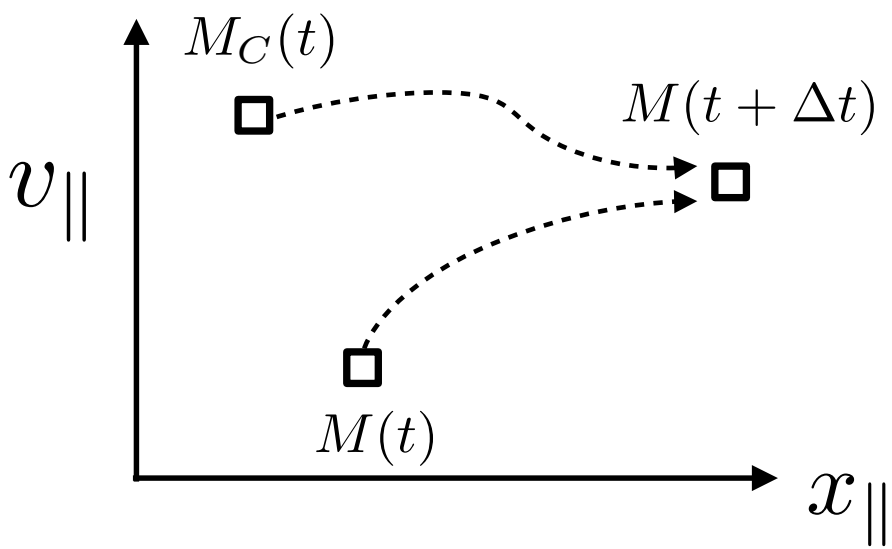
Hybrid Method: Decomposition & (De)Thermalization





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

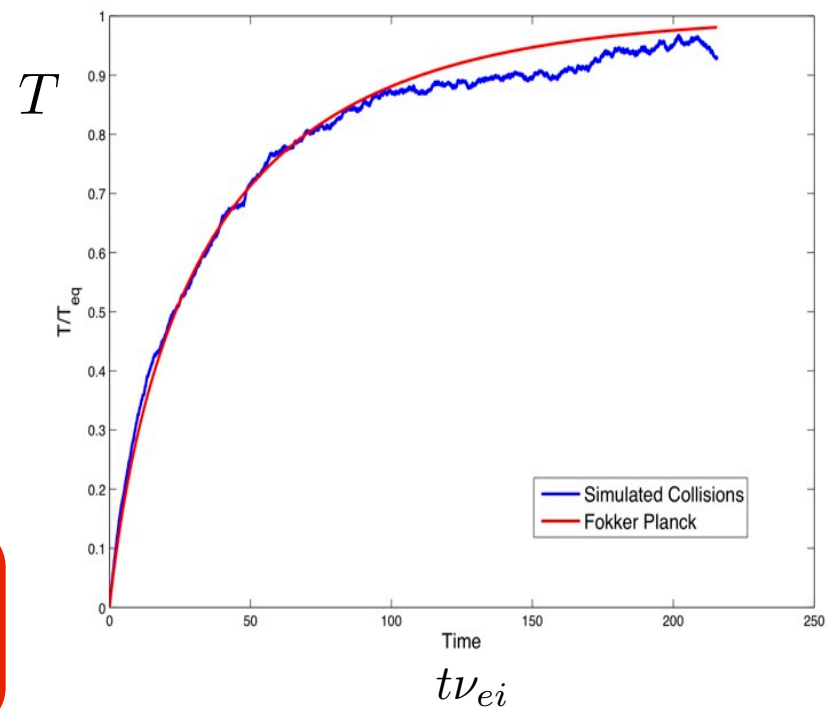
Hybrid Method: Decomposition & (De)Thermalization



$$\Delta M = M(t+\Delta t) - M_C(t)$$

- ΔM: Lagrangian change
- Kinetic 'Forcing' dethermalizing

- Particle passive-scalars
- Entropy based thermalization



1. Ricketson, Dimits, Rosin, Cohen, Caflisch, *Work in Progress, 2011*

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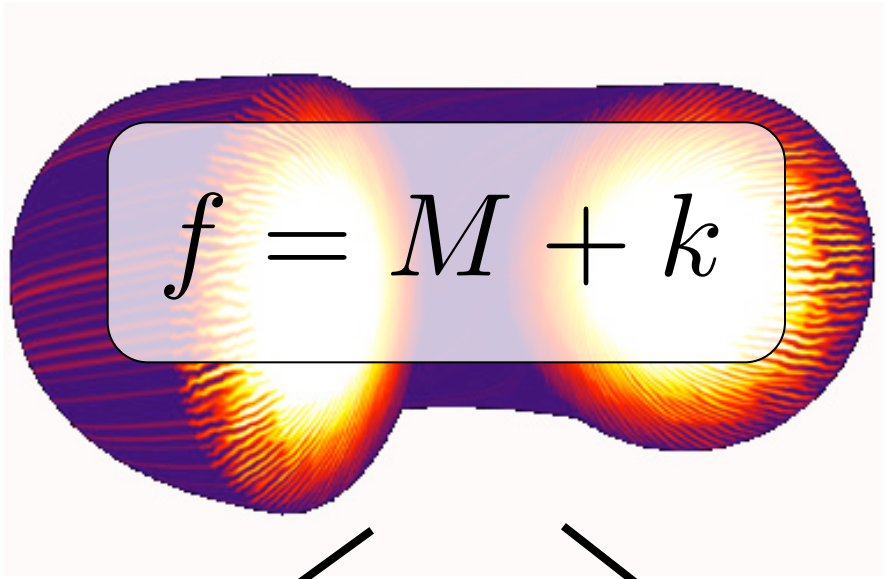
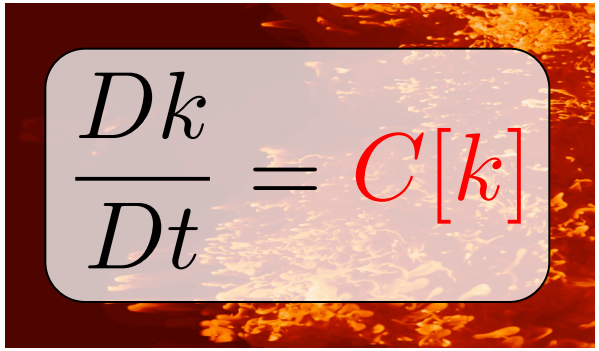
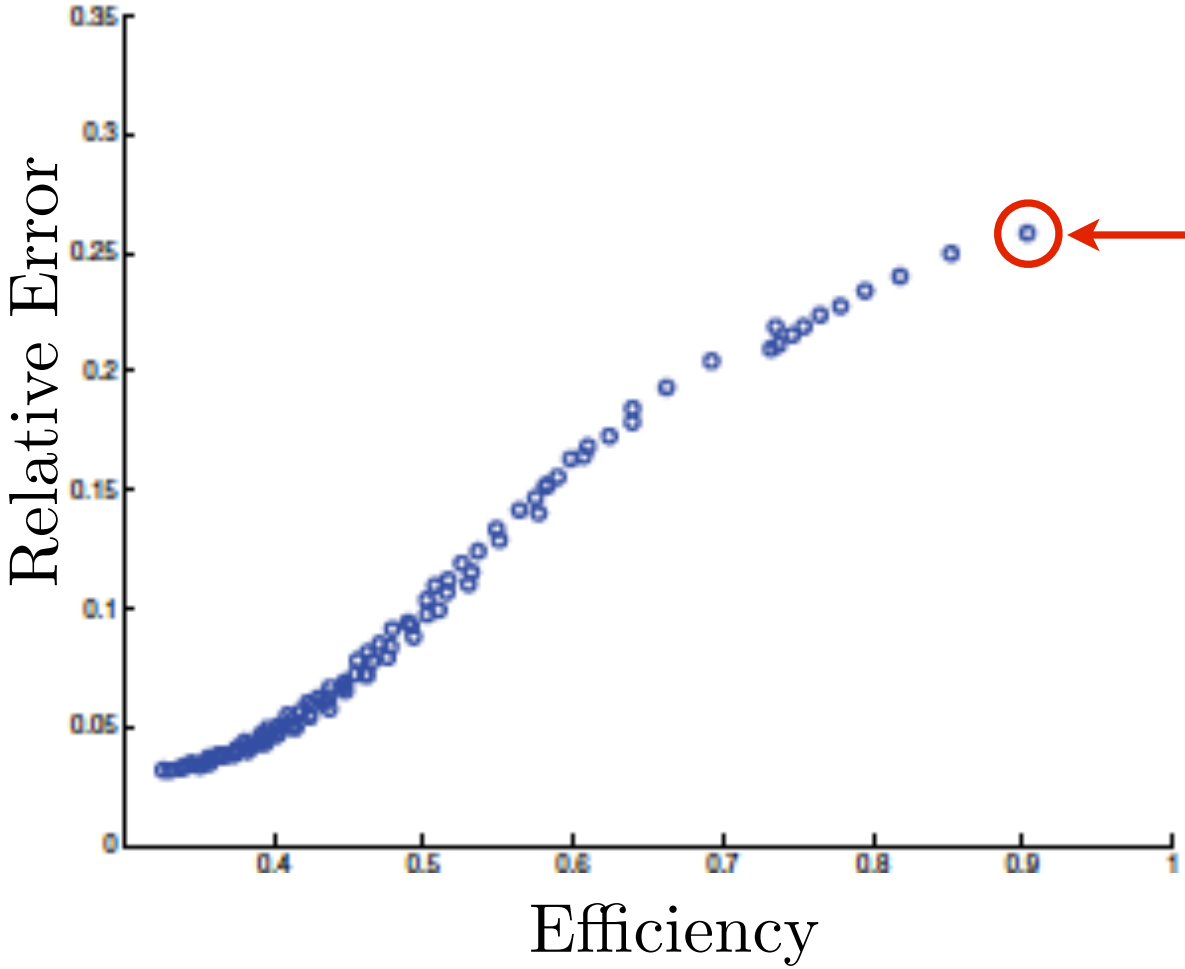
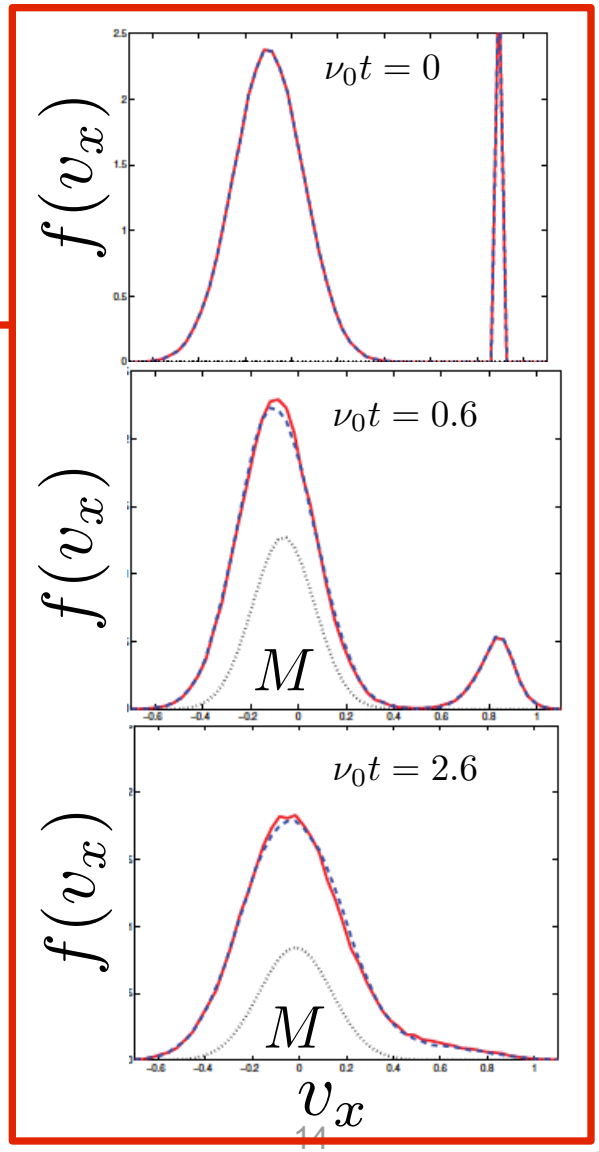




Hybrid Test Case: Bump-On-Tail





1. Caflisch, Wang, Dimarco, Cohen, Dimits, 2008, *SIAM,* 7-2, 865

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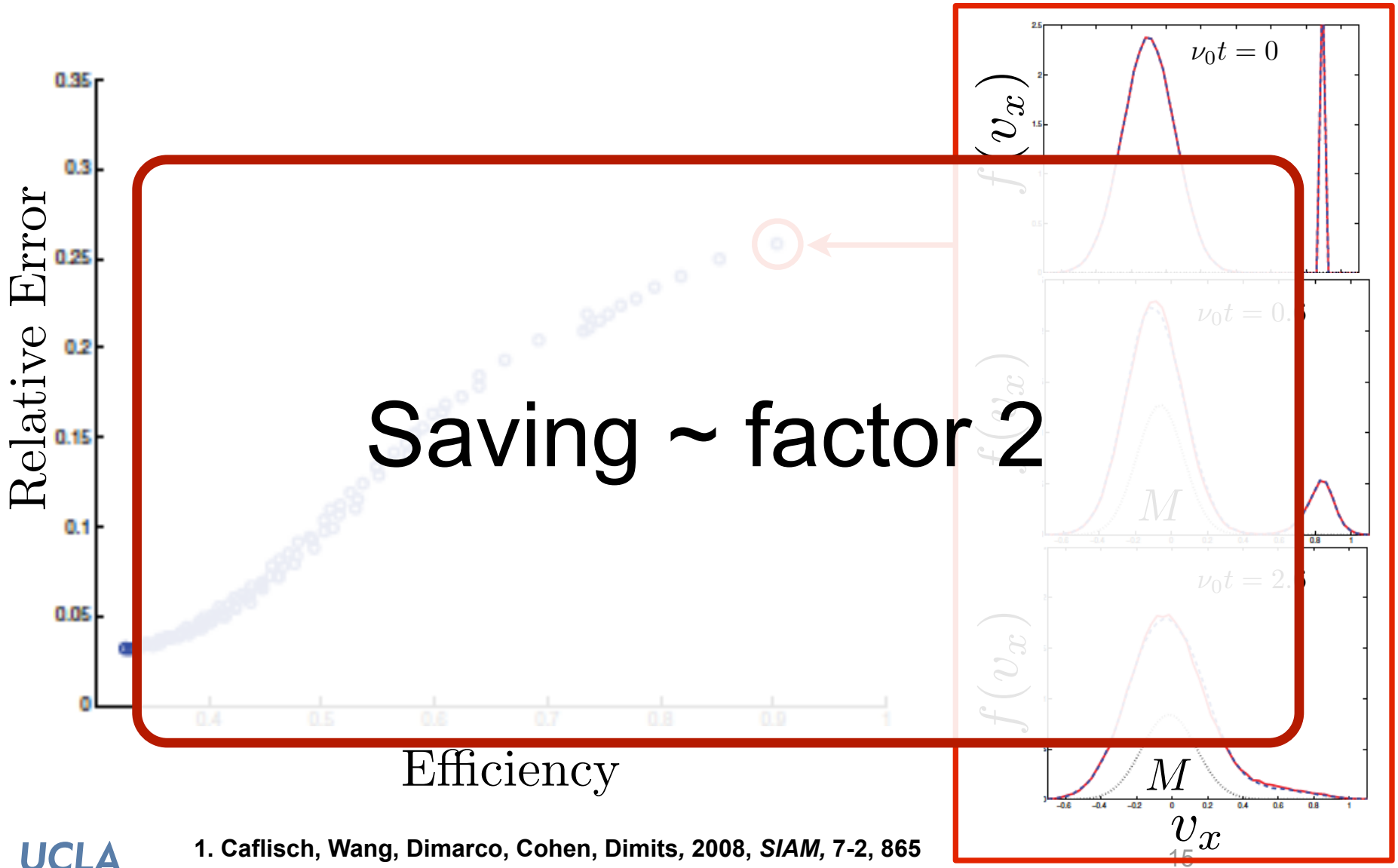
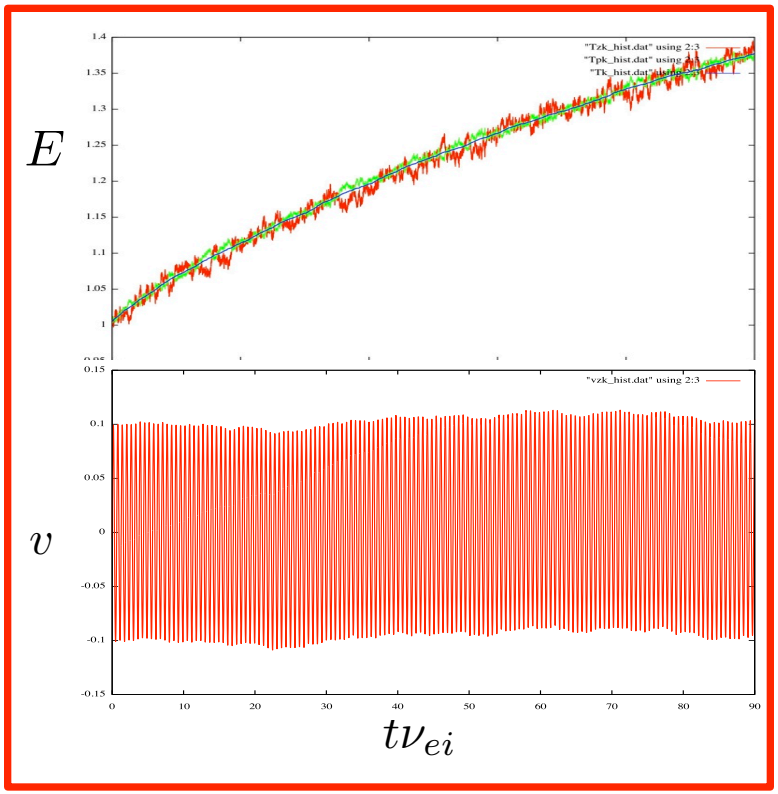


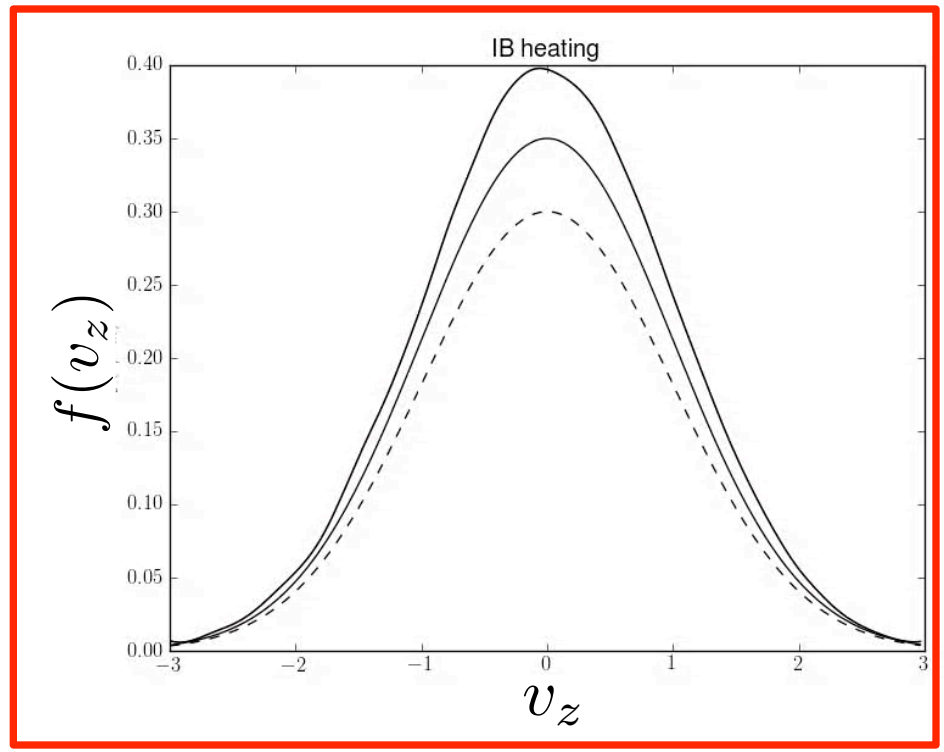
Saving ~ factor 2

1. Caflisch, Wang, Dimarco, Cohen, Dimits, 2008, *SIAM,* 7-2, 865

Hybrid Test Case: Inverse-Bremsstrahlung Heating

- Oscillating laser electric field
- Collisional ion-electron heating





1. Rosin, Dimits, Cohen, Caflisch, *Work in Progress, 2011*

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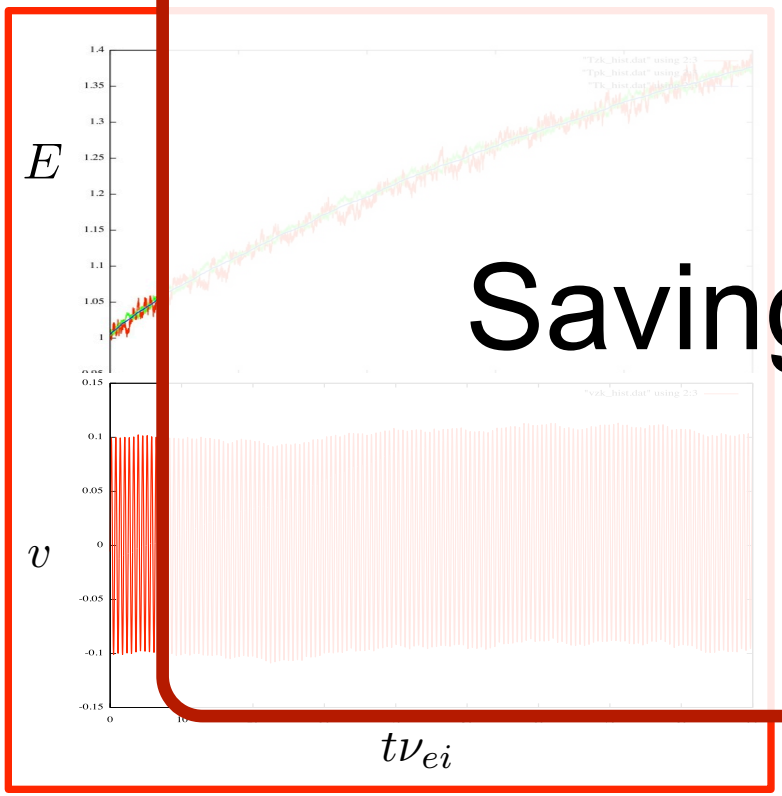

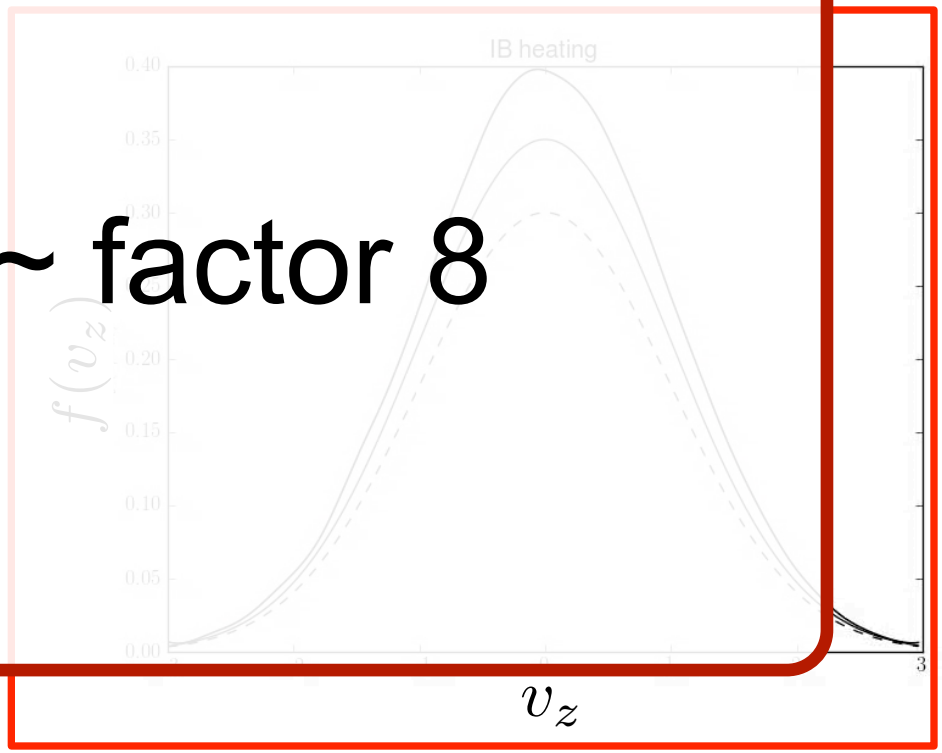

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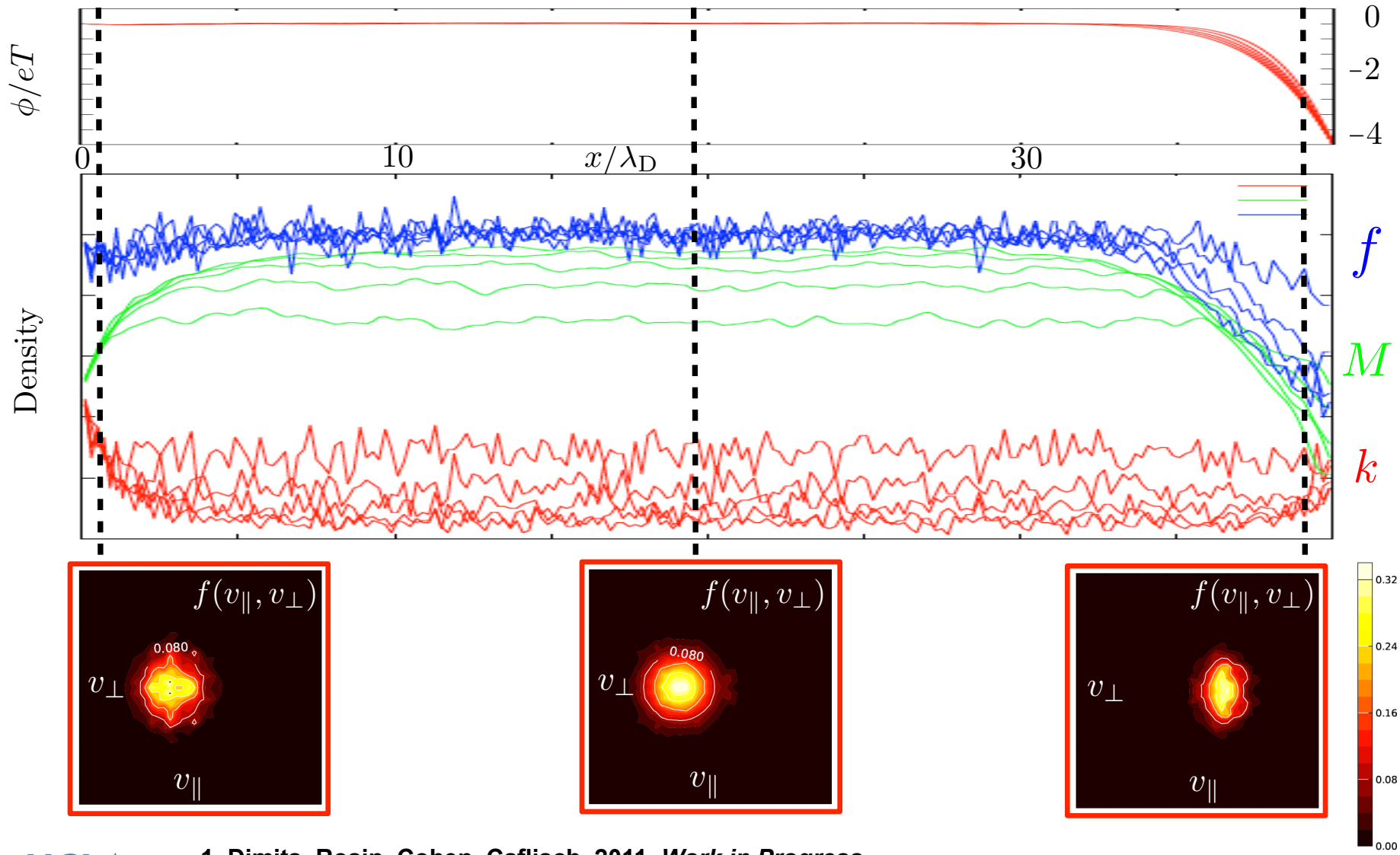
1. Rosin, Dimits, Cohen, Caflisch, *Work in Progress, 2011*

Hybrid Test Case: Electric Sheath



1. Dimits, Rosin, Cohen, Caflisch, 2011, *Work in Progress*

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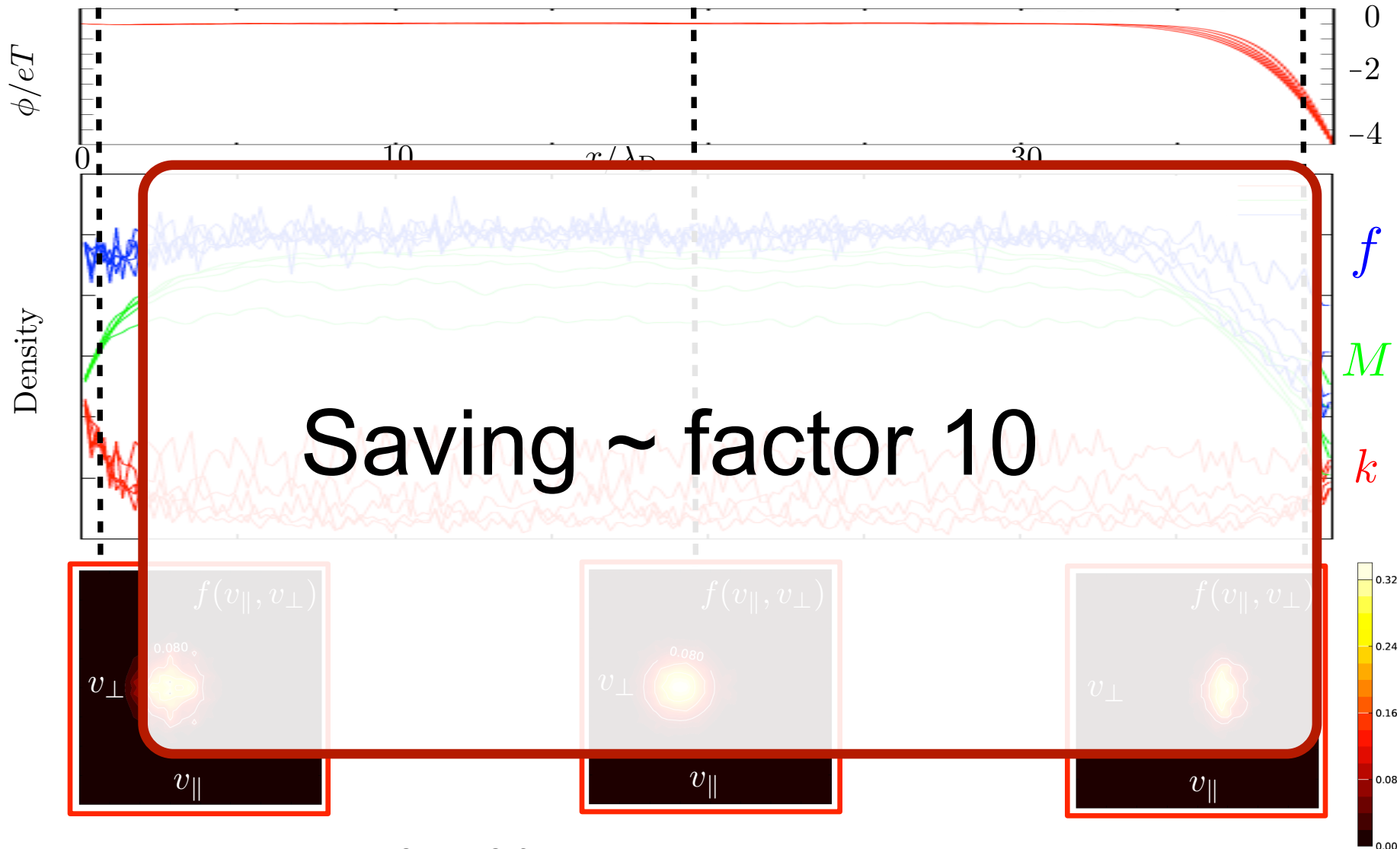

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1. Dimits, Rosin, Cohen, Caflisch, 2011, *Work in Progress*

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 collisons
- Dynamically combine multiple problem sets
- Extend hybrid method to transport equations

Further Progress at APS DPP (Nov)