Vlasov kinetic modeling and studies of plasma transport during ELMs in Tokamak

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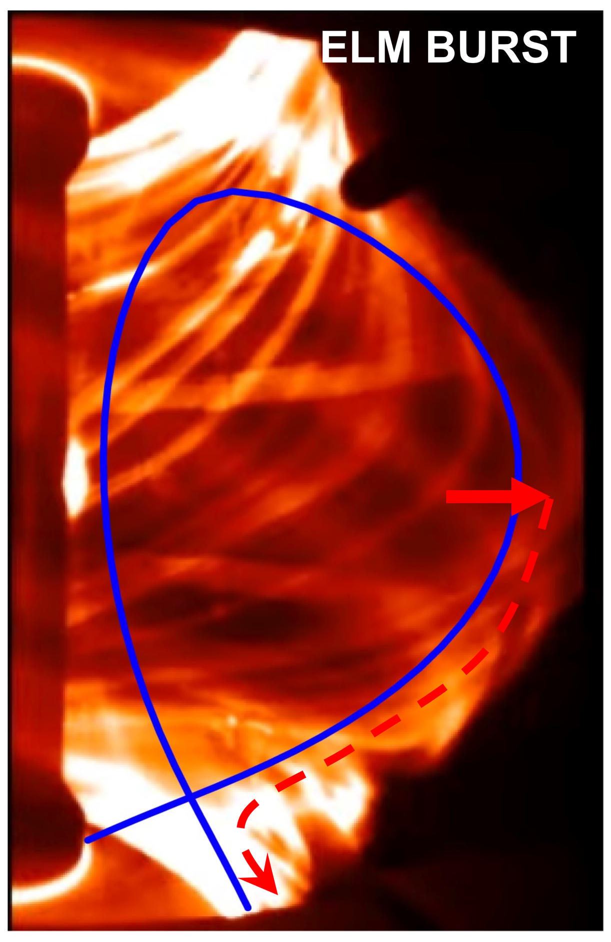
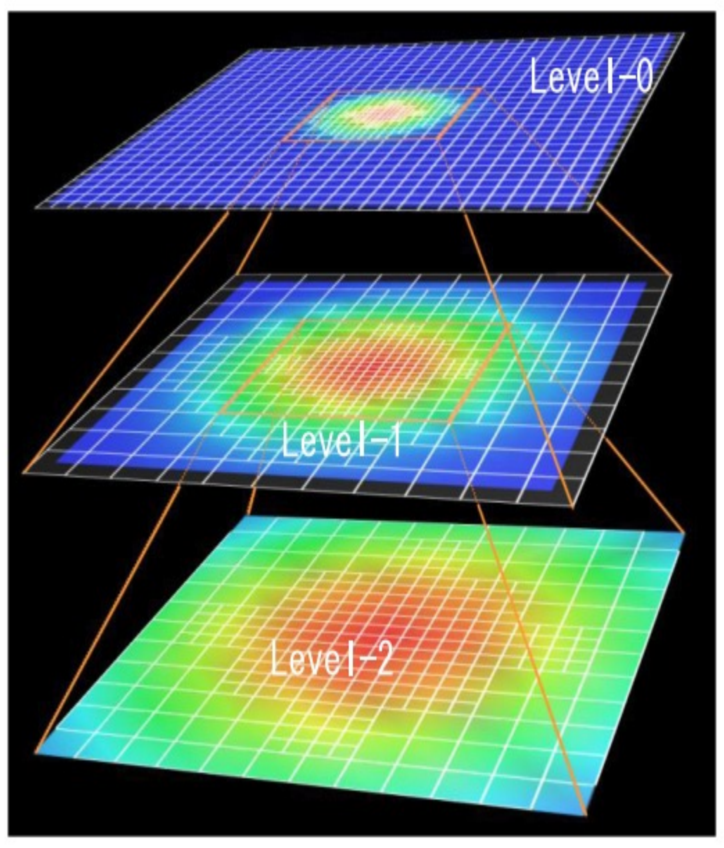
1. MOTIVATION

ELM bursts produce intense transient heat loads on divertor targets

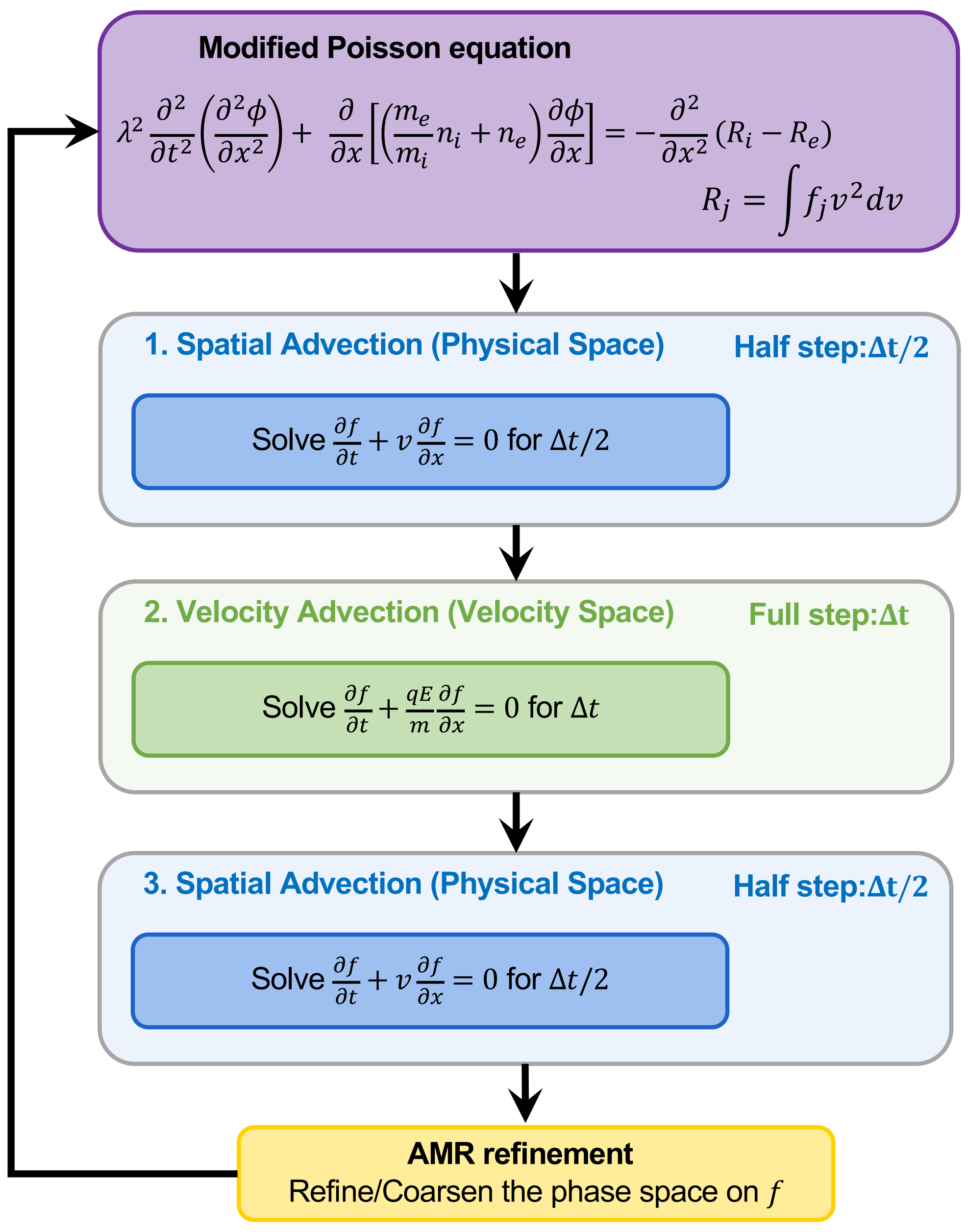
✓ Vlasov + AMR





Sheath-resolved
Noise-free
Memory-efficient

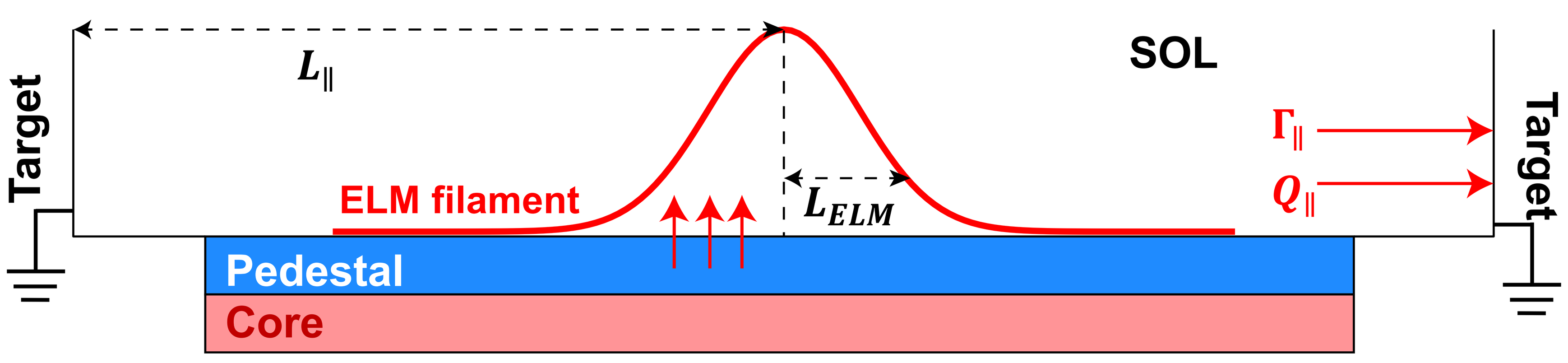
2. KOBRA



- Finite-volume Vlasov-Poisson code
- Adaptive mesh refinement **AMR** in phase space [1]
- Quasi-neutral version solving a modified Poisson equation [2]

3. NUMERICAL SETUP

ELM modelled as gaussian perturbation

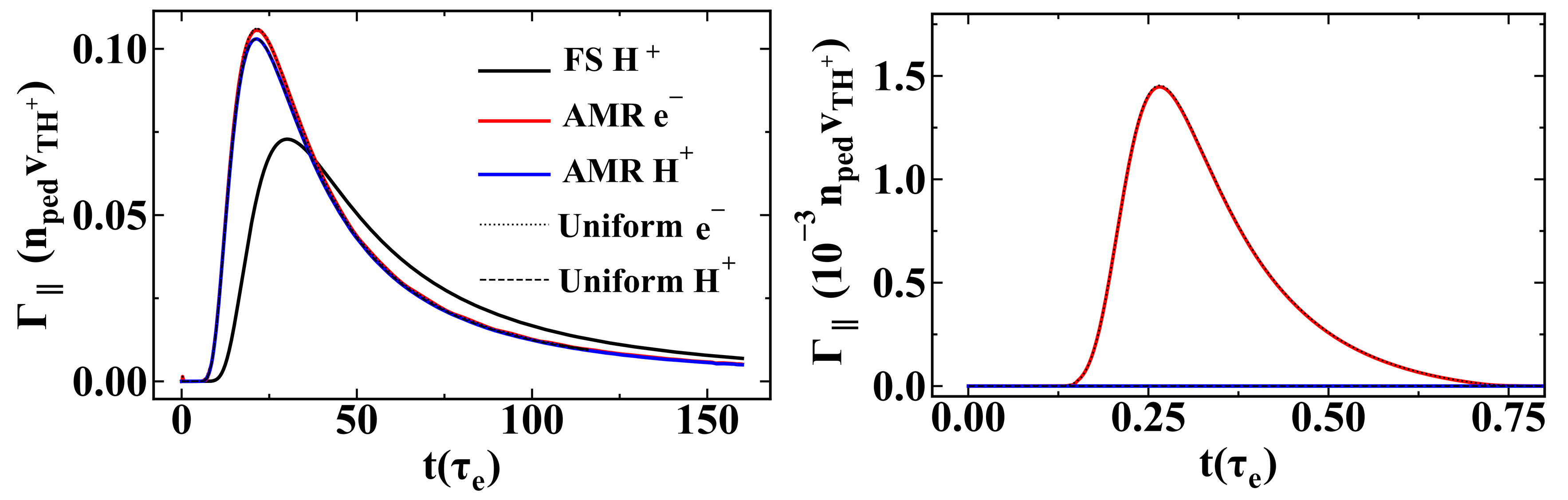


- Background parameter on JET [3]
  - ✓ $T_{ped} = 400\ eV$
  - ✓ $n_{ped} = 3.2{\times}10^{19}\ m^{-3}$
  - ✓ $L_\parallel = 10\ L_{ELM} = 30\ m$
- Simulation parameter
  - ✓ Uniform: 1024×1024
  - ✓ AMR: 4-level with initial grid 64×64

4. RESULTS

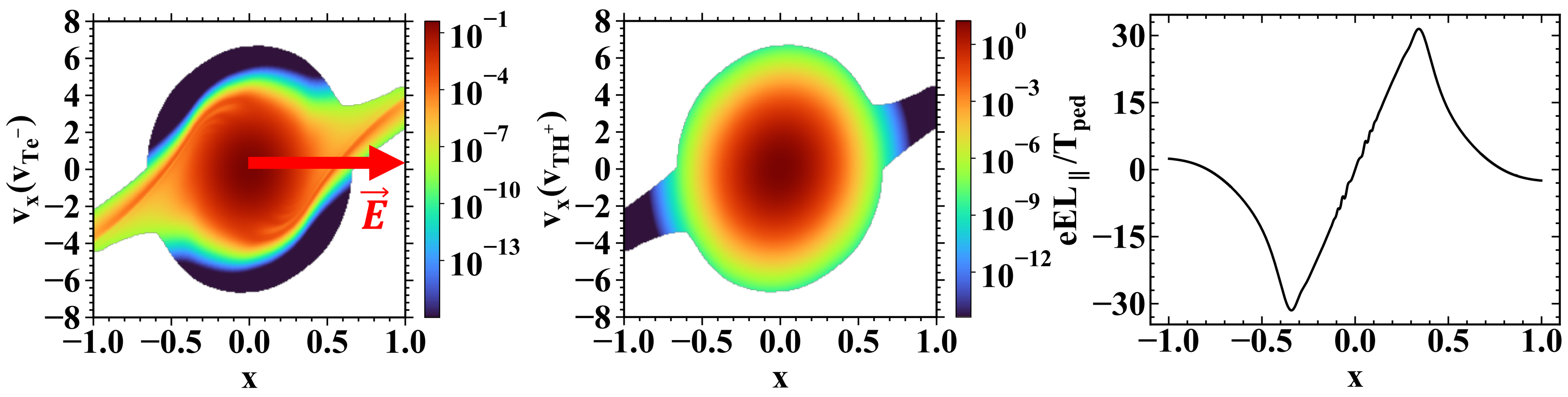
4.1 AMR vs UNIFORM ACCURACY

Relative error <<1%

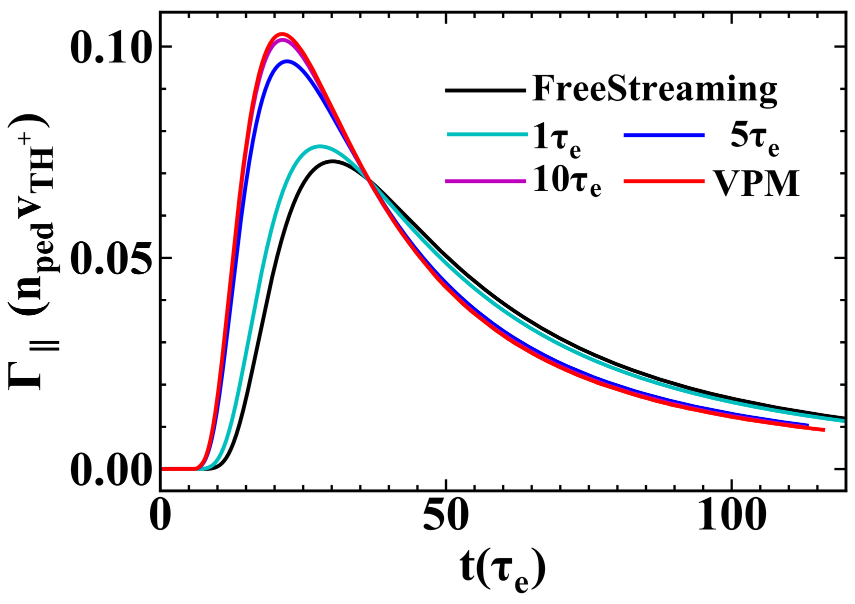


AMR reproduces the uniform-grid solution

4.2 PHASE-SPACE STRUCTURES AT $0.5\tau_e$



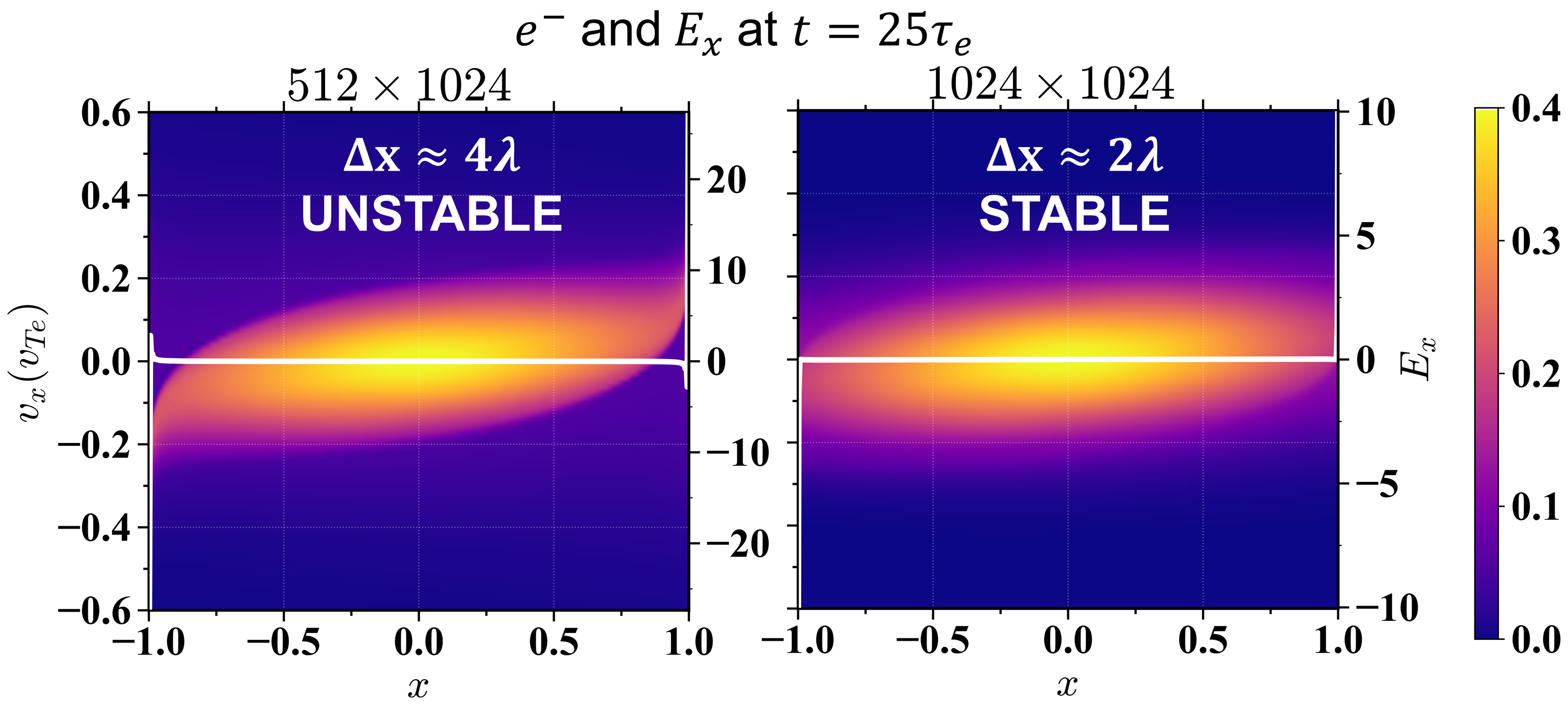
4.3 QUASI-NEUTRAL STATE AFTER $\sim 7-10\tau_e$



- VPM: full Vlasov-Poisson
- Colored curves: VP → free-streaming ions after $1, 5, 10\ \tau_e$
- Initial electric field keeps ions and electrons moving together

4.4 SHEATH LENGTH $l_{sheath} \approx 2\sim3\lambda_D$

e^- and E_x at $t = 25\tau_e$

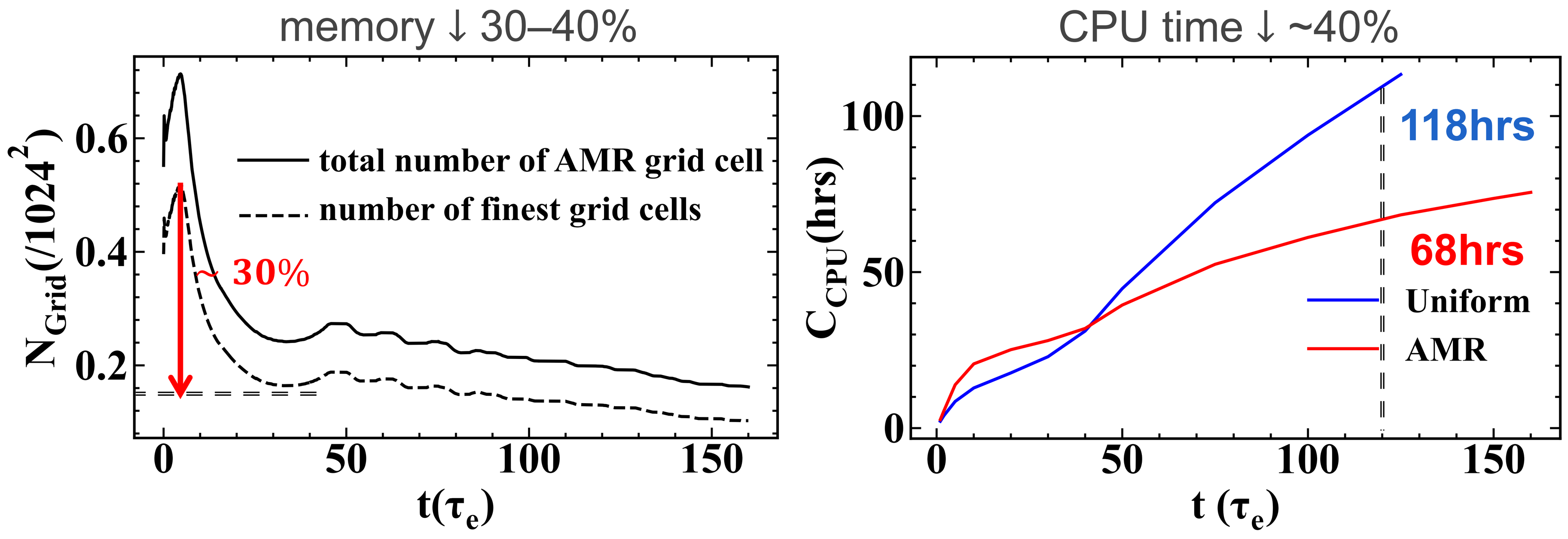


It is necessary to resolve the plasma sheath near the wall!

4.5 COMPUTATIONAL EFFICIENCY

memory ↓ 30–40%

CPU time ↓ ~40%



5. CONCLUSION

- ✓ AMR reproduces uniform-grid solutions with relative errors below 1%
- ✓ A quasi-neutral state is established after $\sim 7-10\tau_e$
- ✓ AMR reduces memory usage by 30–40% and CPU time by ~40%

References: [1] Wareing et al., MNRAS 2016 | [2] Degond et al., JCP 229, 5630 (2010) | [3] Manfredi et al., PPCF 53, 015012 (2010)