GPGPU Adaptive Ray Tracing for Radiation Transport in the Nyx Cosmological Simulation Code

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Introduction

- Numerical radiative transfer codes play a key role in the study of the Epoch of Reionization. (~300-800 Myr after Big Bang.)
- Ray tracing (RT): accurate / slow
  - Moment-based: more approximate / faster
  - Semi-numerical: most approximate / fastest
- Full self-consistency → RT needs to be coupled to hydrodynamical simulation, N-body.

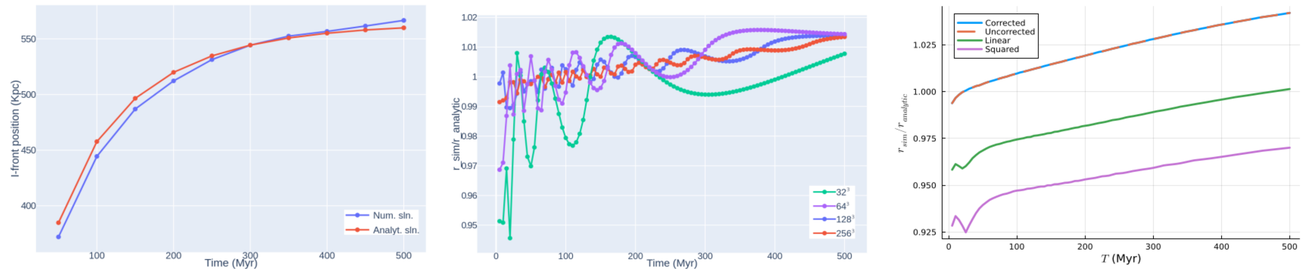
Past Literature

- Most prior work on RT is
  - On CPU
  - Small / medium scale
- Most prior GPU work is:
  - CUDA-specific
  - not coupled to hydro /N-body
  - Small / medium scale

Contribution

1. GPU implementation of RT atop AMReX [1] library, which provides abstractions for:
   - Performance portability
   - Distributed memory scalability
   - AMR
2. Native integration with Nyx cosmology sim.
3. Verification vs. analytic + numerical solutions.
4. Solution to edge case when using geom. correction proposed by [3] with cells of low H number density.

Preliminary Results



(a) Analytic comparison (b) Mesh convergence study (c) Geometric correction comparison

Fig. 1: Spherical symmetry test results. (a) Comparison of radius evolution solution over time using for Test B. (b) Grid refinement convergence study, Test B. (c) Test A w/different choices of geometric correction.

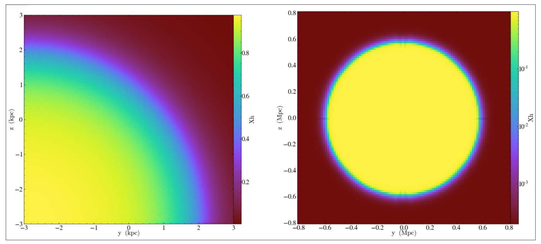
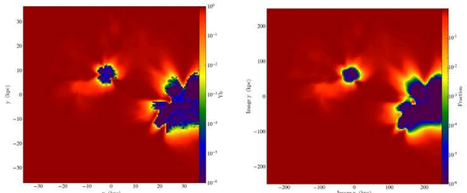
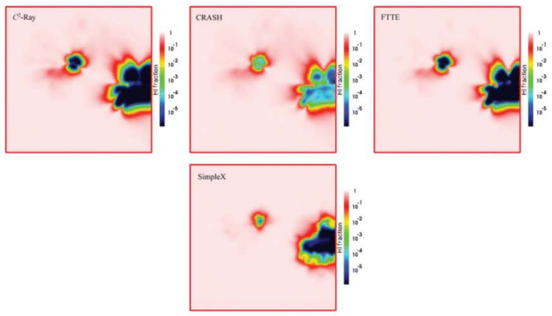


Fig. 2: Ionization fraction at t=500 Myr for Tests A (left) and B (right).

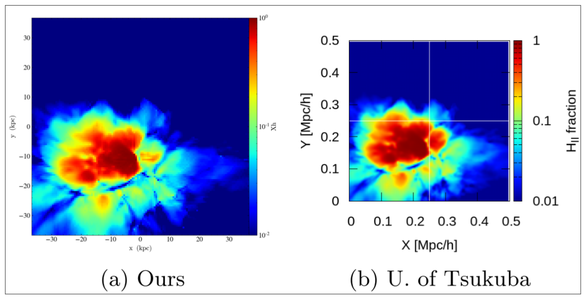


(a) Ours (b) ARC



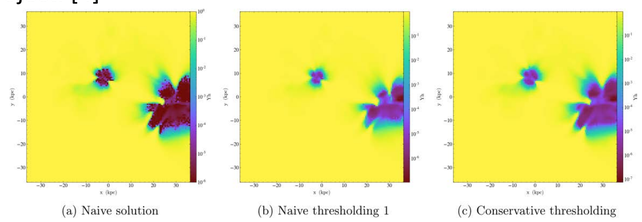
(c) Iliev et al., 2006

Fig. 3: Ionization fraction at t=0.05 Myr for "Test 4 of the Cosmological Radiative Transfer Comparison Project. [4]



(a) Ours (b) U. of Tsukuba

Fig. 4: Ionization fraction at t=0.04 Myr with U. of Tsukuba's initial conditions.



(a) Naive solution (b) Naive thresholding 1 (c) Conservative thresholding

Fig 5: Comparison of "Test 4" results given different solutions to the "low H number density edge case."

Future work

1. Scaling to larger volumes, many nodes, many sources.
2. Full-scale cosmological simulation run with the Nyx cosmology code.

Citations

[1] Zhang, Weiqun, et al. "AMReX: a framework for block-structured adaptive mesh refinement." *The Journal of Open Source Software* 4.37 (2019): 1370.
[2] Almgren, Ann S., et al. "Nyx: A massively parallel amr code for computational cosmology." *The Astrophysical Journal* 765.1 (2013): 39.
[3] Hartley, Blake, and Massimo Ricotti. "ARC: adaptive ray-tracing with CUDA, a new ray tracing code for parallel GPUs." *Monthly Notices of the Royal Astronomical Society* 483.2 (2019): 1582-1598.
[4] Iliev, Ilian T., et al. "Cosmological radiative transfer codes comparison project–I. The static density field tests." *Monthly Notices of the Royal Astronomical Society* 371.3 (2006): 1057-1086.