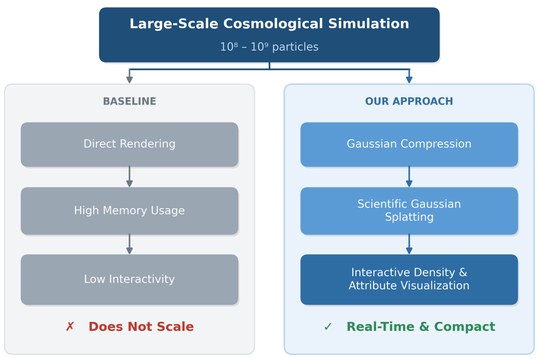
FIELD-PRESERVING GAUSSIAN SPLATTING FOR INTERACTIVE VISUALIZATION OF LARGE-SCALE COSMOLOGICAL SIMULATIONS

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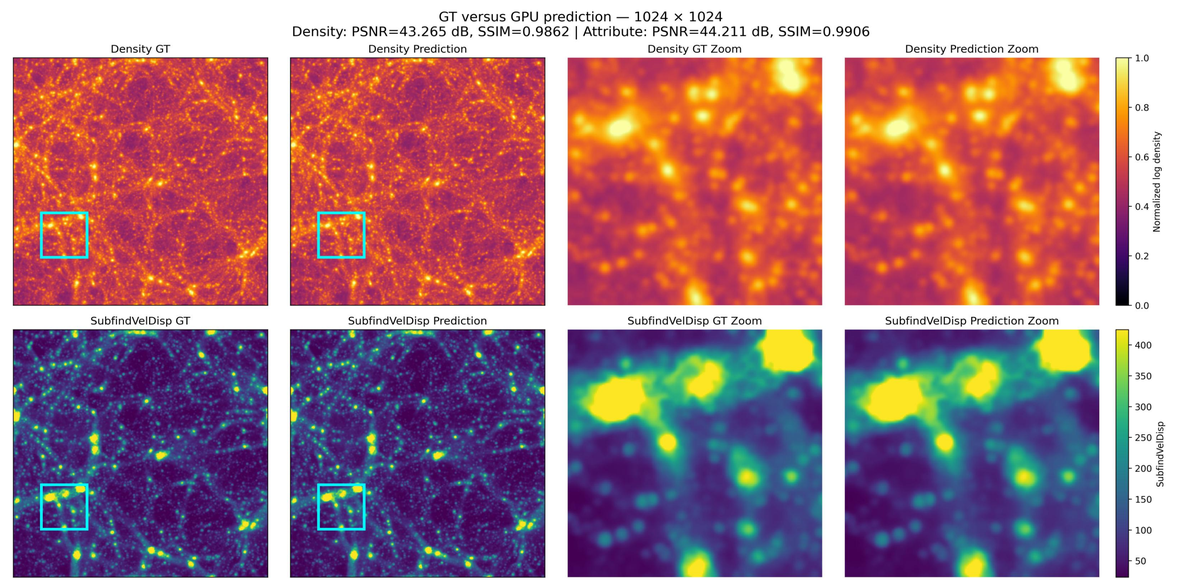
INTRODUCTION AND MOTIVATION

- Large-scale cosmological simulations (Illustris-3, HACC) generate hundreds of millions to billions of particles, making interactive visualization expensive.
- Gaussian Mixture Models (GMMs) efficiently compress particle datasets, but existing GMM renderers rely on depth-plane sampling and alpha compositing, increasing rendering computational overhead [1].
- Existing Gaussian Splatting achieves real-time rendering but is designed for photorealistic graphics rather than preserving scientific fields [2].
- We propose a GPU-accelerated field-preserving Gaussian splatting framework that combines GMM compression with customized scientific rasterization for interactive visualization of cosmological particle data.



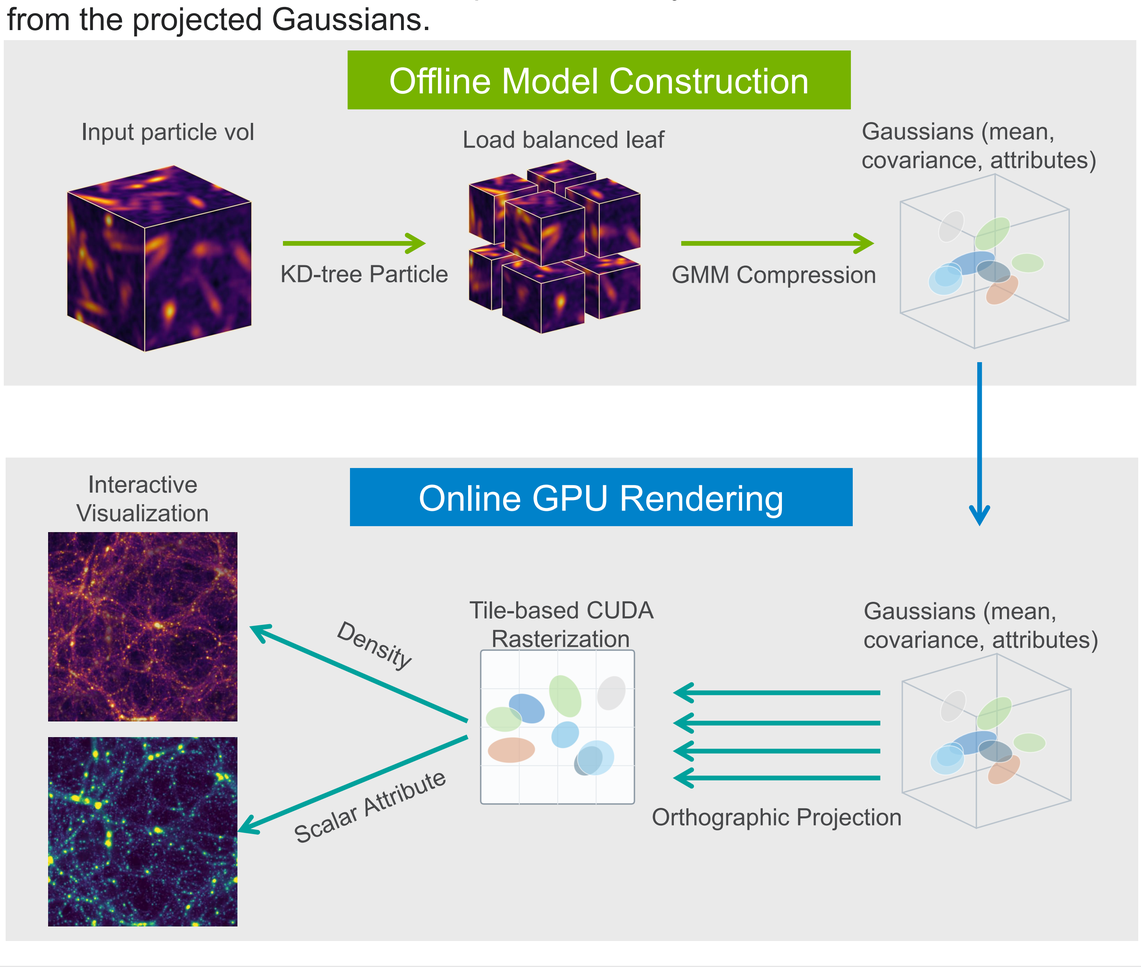
ILLUSTRIS-3 DENSITY AND ATTRIBUTE

- **Dataset:** Illustris-3 dark matter simulation (~9.4×10^7 particles) PartType 1
- **Compression:** 1% Gaussian representation (524,288 Gaussians)
- **Goal:** Reconstruct particle density and velocity-dispersion fields while maintaining interactive rendering performance.



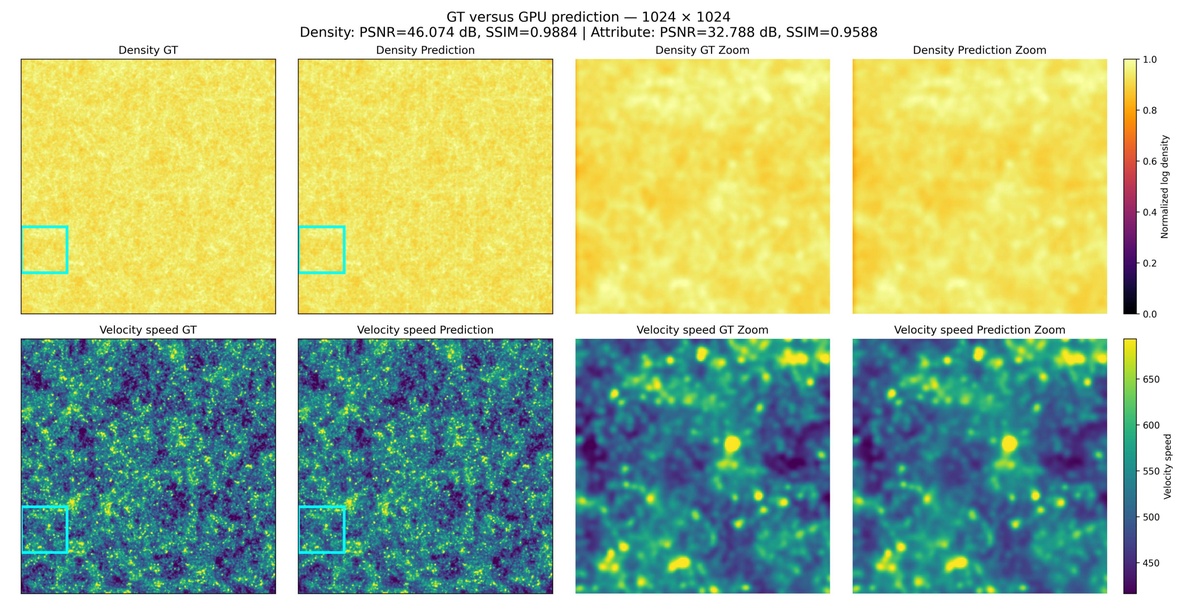
METHODS

- **Hierarchical GMM Construction:** Partition the particle dataset using a KD-tree and fit local Gaussian Mixture Models (GMMs) to obtain a compact scientific Gaussian representation.
- **Orthographic Projection:** Project Gaussian primitives from 3D object space to the 2D image plane using the gsplat CUDA projection pipeline.
- **Field-Preserving GPU Rasterization:** Extend the gsplat tile-based CUDA rasterizer to reconstruct additive particle density and conditional scalar attributes from the projected Gaussians.



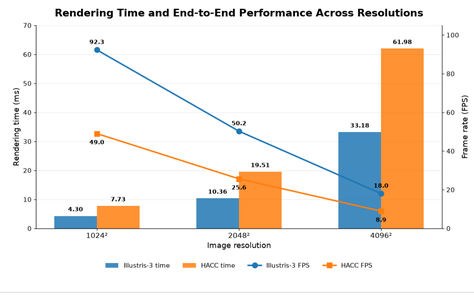
HACC SCALABILITY AND PERFORMANCE

- **Dataset:** HACC *m000* simulation (~3.3×108 particles)
- **Compression:** 1% Gaussian representation (1,048,576 Gaussians)
- **Objective:** Demonstrate scalable interactive visualization for large-scale cosmological simulations



Our renderer accurately reconstructs large-scale density structures and velocity fields while enabling interactive visualization of a simulation containing more than **330 million particles.

SUMMARY RESULTS



ACKNOWLEDGEMENT

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CONCLUSIONS & FUTURE WORK

- **Field-preserving Gaussian splatting** for interactive visualization of compressed cosmological particle datasets.
- **High-fidelity reconstruction** of additive particle density and continuous scalar attributes.
- **Interactive rendering** of up to **92 FPS** for datasets containing over **330 million particles**.
- **GPU-accelerated scientific renderer** built on the **gsplat** CUDA framework.
- **Future Work:** Extend the framework to **time-varying datasets**, **distributed multi-GPU rendering**, and **learned Gaussian representations**.

NEXT STEPS

- **Multi-attribute Rendering:** Extend the framework to simultaneously reconstruct multiple physical quantities (velocity, temperature, and density).
- **Adaptive Gaussian Compression:** Develop adaptive fitting strategies that allocate Gaussian components according to local data complexity.
- **Time-Varying Visualization:** Extend the renderer to support interactive exploration of time-dependent cosmological simulations.
- **Extreme-Scale Rendering:** Investigate out-of-core and distributed GPU rendering for trillion-particle datasets.

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